AD-A215 461

WINTER FISH POPULATIONS IN PROBABLE LOCATIONS OF AIR BUBBLERS IN THE ST. MARYS RIVER-LAKE SUPERIOR AREA

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Contract Number 14-16-0009-79-087

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This study was funded by the
U.S. Army Corps of Engineers under the
Corps/FWS Agreement No. NCE-IS-78-36.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) FWS/OBS 80/60	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION NUS Corporation 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Fish and Wildlife Service
6c. ADDRESS (City, State, and ZIP Code) NUS Corporation 1910 Cochran Road Pittsburg, PA 15220	7b. ADDRESS (City, State, and ZIP Code) Federal Building, Fort Snelling Twin Cities, MN 55111
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER NCE-IS-78-36
8c. ADDRESS (City, State, and ZIP Code) P.O. Box 1027 Detroit District Detroit, MI 48231	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Winter Fish Populations in Probable Locations of Air Bubblers in the St. Marys River - Lake Superior Area

12. PERSONAL AUTHOR(S)
Dahlberg, M.D., J.W. Duncan, and J.M. Burke

13a. TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	September 1980	131

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	reconnaissance trip, gill, hoop and fyke netting, set lines, radio telemetry sonar studies, benthic macroinvertebrates, physicochemical parameters

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A series of field studies were conducted by NUS Corporation in five areas where air bubbler sites were proposed for the St. Marys River and Whitefish Bay to keep channels ice free for winter vessel passage. The studies were done to determine base line ecological conditions and the effects of the bubblers on respective fish and benthic communities.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Jimmie L. Glover	22b TELEPHONE (Include Area Code) (313) 226-7590 22c OFFICE SYMBOL CENCE-PD-EA

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

EXECUTIVE SUMMARY

1. NUS Corporation conducted a winter (1979-1980) survey of fish, benthic macroinvertebrates and selected physicochemical parameters at five bubbler sites proposed for the St. Marys River and Whitefish Bay. Two bibliographies were also prepared and are included as appendices to this report. Subjects were: "Ecological effects of air bubblers in the winter, a partially annotated bibliography" and "Annotated bibliography on winter fish and macrobenthos communities of St. Marys River, Lake Superior and Lake Huron."

2. A reconnaissance trip in October 1979 was used to test sampling gear and collect fall benthos samples. Open water sampling was conducted during December and ice cover sampling during late January, February and March.

3. Gill netting yielded 97 fish in shallow waters close to the navigation channel. Catch-per-unit-effort (CPE) was 2.16. At the deeper bubbler site stations, gill nets yielded 188 fish for a lower CPE of 0.64. Medium and large fish dominated the river catches, the most abundant being cisco, northern pike and burbot. Catch rate was highest in 114 mm mesh with fine 110/3 twine. Fyke nets were not effective in the deeper water.

4. Set lines baited with frozen rainbow smelt were highly selective for burbot; 133 burbot were caught in 336 24-hr sets (CPE = 0.40).

5. Radio telemetry was used to track movements of 8 burbot, 5 white suckers, 1 longnose sucker, 3 northern pike and 1 whitefish. In addition, one tagged walleye left the study and two tagged fish died when recaptured in gill nets. Predominant movements were characterized as local, upstream and downstream. The maximum distance recorded was 6.7 km in 32 days. One northern pike had traveled 7.5 km to the east before it was captured by an angler on May 24, 1980 and another was captured 16 km upstream on July 22, 1980.

6. Strip chart recordings of a Ross Fine Line sonar unit demonstrated that the density of fish populations at the river bubbler sites was generally very low. Fish were detected and counted on five occasions and there was extensive movement through the transducer beam at Station 3 on the night of March 4. Direction of movement was not determined.

7. The dominance of immature midges (Chironomidae), worms (Oligochaeta) and snails and clams (Mollusca) was illustrated in this and previous studies of the St. Marys River macrobenthos. Densities were relatively low in the navigation channel at the proposed bubbler sites.

8. Baseline data were produced for selected physicochemical parameters: water temperature, turbidity, dissolved oxygen and velocity.

9. Bubbler systems designed to exclude fish from water intakes have not been successful. A bubbler system designed to reduce ice cover would not produce a complete wall of bubbles and would not have an adverse effect on fish or macrobenthos in flowing waters.

This report was submitted in fulfillment of Contract Number 14-16-0009-79-087 by NUS Corporation under the sponsorship of the Office of Biological Services, U.S. Fish and Wildlife Service. Work was completed as of 8-31-80.

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We thank the many local residents who assisted us in the field w… particularly William Miller, Robert Andrews, Paul Merchberger Jr., Paul Merchbe… Sr. and Ralph Wilcox Jr., and others who provided information on field sampling techniques, particularly Wayne Crayton, Thomas Edsall, Dennis Dunning, James Wuebben, David Behmer, Walter Duffy, James Winter, Jon Ross, John Gagnon and Keith Kraai.

INTRODUCTION

The St. Marys River is the outlet of Lake Superior and flows into Lake Hu . Traditionally the Soo Locks of the St. Marys River and the St. Lawrence Seaway have been closed to navigation from about December 15 to early April. The year 1979 was the eighth of a Federally supported program to determine the Federal interest in a permanent program to extend the navigation season on the Great Lakes - St. Lawrence Seaway (U.S. Army Engineer District, Detroit 1979). Extensive participation of Federal, State and local agencies, interest groups, and concerned citizens has occurred since the study was authorized in 1970. Many ecological studies have been conducted to determine what impacts may result from winter navigation. The proposal to operate five large bubbler systems in the St. Marys River and Whitefish Bay, to reduce ice cover, aroused concern regarding potential effects on the fishes and aquatic invertebrates. In 1979, NUS Corporation contracted with the U.S. Fish and Wildlife Service for this study to determine, through field and literature studies, baseline ecological conditions at the proposed bubbler sites and potential effects of the bubblers.

METHODS

The study area ..ated in the U.S. waters of the St. Marys River and Whitefish Bay (Figure 1). Samples were collected along proposed bubbler lines in the St. Marys River as shown in Figures 2-5. Stations were designated as follows:

Station	Location	Length of bubbler (ft)
1	Angle course turn 8-9, Johnson Point	10,000
2	Angle course turn 7-8, Mirre Point	5,000
3	Angle course turn 6-7, Hen and Chicken Islands	5,000
4	Angle course turn 5-6, head of Neebish Island	3,500
5	Birch Point Turn, Whitefish Bay	3,500

Gill nets were also set in shallow waters near Hen Island primarily to collect additional fish for fish tracking studies.

RECONNAISSANCE TRIP

A reconnaissance study was made during October 2-6, 1979 to compare the efficiency of different types of sampling gear, compare results of gill nets set parallel and perpendicular to the current, establish alternative but representative stations in case the target area was not accessible part of the time, collect the autumn benthos samples, and establish a field laboratory in Barbeau, Michigan.

In October, hoop nets and fyke nets set at 3.7 m, 5.5 m and 6.1 m depths were effective for smaller fish such as rock bass (Ambloplites rupestris) and young smallmouth bass (Micropterus dolomieui) but not for larger fish (Tables 1-4). Gill nets appeared to be more effective for certain sport fish such as walleye (Stizostedion vitreum) and northern pike (Esox lucius) but the limited sampling was inconclusive. This survey did show that gill nets could be set perpendicular to the current, as well as parallel, over the velocity range encountered (0.4-0.9 fps).

The use of alternative but representative river stations had been a consideration because of the periodic difficulty and danger involved in sampling along the edge of the navigation channel. However, sampling along the proposed bubbler lines was implemented successfully.

GILL NETTING

Gill nets were set from boats in October, December and early January. Due to the extremely mild winter, there were alternating periods of thin ice and drifting ice on the river during most of January. The unusual persistence of these conditions prevented sampling from a boat or on the ice during this period. Under ice sampling commenced January 23 at Station 2, January 25 at Station 1, January 26 at Station 3 and February 4 at Station 4. Variation in time of ice development was related to differences in velocity of current among the stations. Similar conditions encountered in the Whitefish Bay study area were compounded by ridges of broken ice, snow cover on thin ice, and patches of open water through February. When snow cover allowed passage through the ridge of broken ice, samples were collected adjacent to the bubbler line at the 5.2-5.8 m depth contours. Intensive sampling resulted in a fishing effort of 720 gill net hours (30 net days) before sampling had to be terminated due to thawing on March 8. Commercial fishing catches were also examined for additional information.

Gill nets were generally set under the ice by three persons. A series of holes, 7.6 m apart in a straight line totaling 4m more than the length of the net, were drilled with a 25 cm ice auger and chain saw. The holes were cleaned out with a chisel bar and scoop. A 61 m running line was attached to the running pole which was pushed along under the ice along the holes. The running board was pulled from the last hole to stretch the line between the end holes. The net was attached to the line and pulled through to set the net. An anchor, and usually a bridle, was also attached to each end of the net. The line was pulled tight on both ends to set the net straight. The anchor ropes were then tied off to a stick set across the hole.

To check the nets, both holes were cleared of ice and the downstream end of the net was pulled up to remove the anchor and attach the running line to the net or bridle. At the upstream end of the net, the anchor was retrieved and the net was pulled through by two persons who removed the fish and placed them in a tub of water. The net was reset by pulling the line through the downstream hole, attaching the anchor, and pulling the net tightly.

When nets were removed for cleaning, a running line was left strung between the holes to facilitate resetting the net. Weights were attached every 6 m to prevent freezing to the ice surface.

The fish were identified, measured (mm), and released alive. A notch was cut on each caudal fin so that recaptures could be identified.

Standard 1.8 m x 46 m nylon experimental nets having a mesh size range of 25 to 178 mm (stretched mesh) were proposed for the study. The scope was expanded to include simultaneous fishing with several 46 m gill nets, each having a single mesh size. Because of the low density of fish populations in the navigation channel, additional steps were taken to increase the catch: long-term fishing as opposed to 48-hr sets, use of monofilament nets, small twine and colored nets, and arrangement of nets in a funnel shape to reduce avoidance. The small 210/2 twine had a 0.23 mm diameter and 7 lbs break test. The 110/3 twine had a 0.20 mm diameter (Nylon Net Company 1976).

Data are expressed as CPE (catch per unit effort) which is defined as the number of fish caught in a single net in approximately 24 hours.

HOOP NETTING AND FYKE NETTING

Fyke nets were used for shallow water winter sampling in the St. Marys River by Poe et al. (1979). Their nets were 4.9 m long, 1.2 m in diameter and had 22.9 m wings. Fyke nets of similar dimensions were used in the present study. The hoop nets were identical but lacking the wings.

SET LINES

Series of set lines were baited with frozen smelt (Osmerus mordax) and checked whenever the gill nets were tended. The bait and lead weight were arranged to maintain the bait slightly off the bottom. Since most of the fish caught were deeply hooked, the leaders were cut to release the fish.

RADIO TELEMETRY

Transmitters (53 MHz, 57 mm, 30 grams) were attached to 21 fish, mostly at Station 3, and tracked with a receiver. Fish collected with gill nets were placed in a partially submerged holding tank in the ice shanty and retrieved for tagging if they appeared to be active. A surgical needle was used to thread the two attachment wires under the dorsal fin (Winter et al. 1978). After further observation in the holding tank, the fish were released and followed for one to several hours using the loop antenna and yagi antenna. The small loop antenna was carried over the ice while the large yagi antenna was set up on and operated from an island next to Hen Island. Flying over the river with the loop antenna mounted on the wing of an airplane proved to be a quick and inexpensive means to locate the tagged fish.

Fish tagging started on February 21 and monitoring continued through March 24. Individual fish were identified by different frequencies. Movements were plotted on maps for analyses (Appendix B).

SONAR STUDIES

A Ross Fine Recorder Model 200 was used to record abundance of fish under the ice. The major components were transducer, transceiver, strip chart recorder, Topaz power converter, and 12 volt marine battery. The transducer operated at 200 KHz and had a beam angle of 22°.

The unit was operated inside a heated ice shanty. The transducer was mounted on a board and suspended below the bottom surface of the ice. The components were then connected by cables. The unit was calibrated by observing strip chart recordings of a test object suspended below the transducer. The sensitivity of the transceiver was adjusted until the plots of the test object reached maximum definition. Best resolution was obtained with the following dial selections: Paper mark 3/4 turn to right, Fineline 9½-10, Depth 0-50 ft, Sensitivity 9, and Paper speed 2. Station, date and time of day were written on the strip charts.

BENTHIC MACROINVERTEBRATES

Triplicate samples of benthic macroinvertebrates were collected with a Ponar grab sampler in October, February and March. Samples were immediately washed in a No. 30 (0.5 mm) mesh and preserved in a 10% formalin solution. This was conducted in a heated shelter in the winter. In the laboratory, samples were sorted into major groups and then identified to levels shown in the Results. All samples have been retained for future reference.

PHYSICOCHEMICAL PARAMETERS

Physicochemical data were collected during the October reconnaissance trip and during the winter fish collecting period. Water samples were collected in the field and refrigerated until analyzed in the laboratory for turbidity (NTU); the determinable limit was 0.01 NTU. Secchi disc readings were also taken as a measure of turbidity. Water temperature, velocity (Marsh-McBirney meter), and dissolved oxygen (Winkler method) were measured in the field.

RESULTS

FISHERY STUDIES

Gill netting

Gill nets were set primarily in waters of the navigation channel where the depth was 8 m or greater to provide baseline condition data for the proposed bubbler locations. Shallower waters in the river were also sampled at Stations 3 and 4, to permit a comparison between shallow and deep waters and to provide additional large fish for telemetry studies.

All catch data are presented in Tables 1-5 and Appendix A. A summary table (Table 6) excludes the shallow water data (Stations 3 and 4) and the October data.

Shallow water close to the navigation channel was fished for 45 net days and yielded 97 fish, for a CPE of 2.16. This is considerably higher than the CPE for the channel sets, as discussed below, although species composition was similar.

At the deeper stations, 188 fish were caught in 376 net days for a CPE of 0.64. At the four river stations, 144 fish were caught in 346 net days for a CPE of 0.42.

The apparently higher catch rate in Whitefish Bay can be attributed to rainbow smelt, a small species which was not commonly caught at the river stations. Northern pike was the second most abundant species at the Whitefish Bay station.

Medium and large fish dominated the river catches, the most abundant being cisco (Coregonus artedii), northern pike, and burbot (Lota lota). Station 3 was the most productive river station (CPE 0.83).

Any possible changes in species composition through the winter were not evident. In combination with fyke net data, there is evidence that walleye and rock bass were more common in the navigation channel in October (fall) than in the winter.

Data were tabulated (Tables 1-5) to permit a general assessment of efficiency of different mesh sizes and twine sizes during the winter. The standard experimental net, with large twine, was relatively inefficient (average CPE was 0.25) and four of the 12 fish caught were rainbow smelt. Average CPE by mesh size for the other nets was 1.30 (25 mm), 0.52 (51 mm), 0.47 (76 mm), 0.74 (114 mm) and 0.28 (127 mm). The 25 mm mesh was highly selective for rainbow smelt. The 114 mm mesh appeared to be the most effective size for larger fish. However, the use of the fine 110/3 twine, and possibly the 210/2 twine, appeared to be the major factor contributing to the effectiveness of the 114 mm mesh. More definitive conclusions are precluded because of the

complex interaction of many factors which affect gill net effectiveness. However, the use of 110/3 twine by commercial fishermen in the study area supports our conclusion.

Gill net data were obtained from a commercial fisherman (Ralph Wilcox) in December and January to supplement our data on species composition in Whitefish Bay. He set 114 mm mesh nets with 110/3 twine near Brimley at depths of 15-31 m. The catch was predominently whitefish (Coregonus clupeaformis) but also included small numbers of cisco, round whitefish (Prosopium cylindraceum), bloater (Coregonus hoyi), chinook salmon (Oncorhynchus tshawytscha), lake trout (Salvelinus namaychus), rainbow smelt, longnose sucker (Catostomus catostomus) and burbot. The gear was highly selective for whitefish and details are not presented herein.

Fyke Net and Hoop Net Studies

Fyke nets and hoop nets appeared to be effective for two species of centrarchids in the early experimental sampling (Table 7) but only relatively small fish were caught. The fyke net was selected for additional winter sampling because the absence of wings would generally make the hoop net less effective. However, winter sets for 96, 48 and 312 hours yielded no fish. The high clarity of the water probably contributed to the ineffectiveness of the fyke net in the winter. The low density of fish in the navigation channel is also a viable factor.

Set Line Survey

The number of 24-hr sets ranged from 42 at Station 5 to 113 at Station 3 (Table 8). Burbot was the only species caught on the frozen smelt used for bait. The 133 burbot caught resulted in a CPE range of 0.17 (Whitefish Bay) to 0.41 (Station 3). These results and the frequency of missing bait provide evidence that the burbot is more numerous than the gill net data would indicate.

Radio Telemetry

All fish used in the tracking study were collected and released at Station 3 with the exception of one longnose sucker (Station 1) and one burbot (Station 4). A net was set at Hen Island near Station 3 to provide more of the larger fish required for tagging. Fish were placed in holding tanks for observation before and after tagging. Although exposure to the cold air was minimized, many of the fish, particularly cisco and whitefish could not recover their equilibrium in the tank and were not tagged.

Of the 21 fish tagged and released at the bubbler site, a cisco, northern pike and white sucker (Catostomus commersoni) were recaptured in gill nets at the station one or two days after release. Only the sucker (#372) was active enough to release again.

With the exception of one walleye which left the area, the fish were successfully tracked as shown in Table 9 and Appendix B. Of the eight burbot tagged, four remained in the area, two moved upstream as far as 5.4 km (27 days) and two moved downstream as far as 4.7 km (6 days).

Three white suckers moved downstream, up to 6.7 km (32 days) and two remained in the area of release. One of the latter (#414) was found 0.5 km upstream after five days and slightly downstream from the point of release 27 days later. The other (#514) was located in the shallows around Hen and Chicken islands four consecutive times and

near the edge of the channel on March 24. The longnose sucker (#114) was located on the Canadian side of the river, 0.3 km from the release point after one week at large.

Three northern pike exhibited different movement patterns. One (#233) released on February 22 was located in the shallows around Hen Island on five occasions and along the bank of the navigation channel on three occasions. The diameter of the circle of eight positions around the island was 0.5 km.

Two northern pike were located between Hen Island and the shoreline after four days at large. On the following day (March 24), both had cro-- the channel to the Canadian side. One (#154) was captured by an angler at Ric rus Landing, St. Joseph Channel (Canada), on May 24, 7.5 km east of the release station. The transmitter was returned by the Ontario Ministry of Natural Resources for verification. The other (#332) was caputred by an angler near Six Mile Point, Lake Nicollet, on July 22, 16 km upstream from the release point (Lloyd Fanter, pers. comm.).

After six days at large, the tagged whitefish (#396) was located between Hen Island and the shoreline. On the following day (March 24) it was located 3.5 km downstream near Mirre Point.

Limited movement, or back-and-forth movement, was evident at times with all of the species tagged except the walleye. The longest movement recorded in February was 1 km (burbot #056). In early March, there were extensive movements upstream by burbot and downstream by two white suckers. In late March there were extensive downstream movements by two burbot, two white suckers and the whitefish. Northern pike movement was predominantly local in February and March, and extensive thereafter judging by the angler captures in May and July.

Sonar Studies

The Ross Fine Line sonar unit recorded the fish entering a conical beam which, at an angle of 22^{o}, covered 15.7 m^2 (diameter = 4.47 m) of bottom at a depth of 9.15 m (30 ft). Actual number of fish was accurately recorded except under the following circumstances. If more than one fish remained at exactly the same depth in the beam, they would be recorded as a single trace. A dense school of fish would also be recorded as a single trace. Thus, the traces represented minimum estimates on March 4 (Table 10, Figure 5).

Surveys at various times of the day demonstrated that the density of fish was very low at the stations in February. Only three fish were recorded in February, all in the evening.

As fish were actively moving by Station 3 on March 4, recordings were made over a four hour period. Approximately 325 traces ranging from small to large were recorded for an average of 81 fish per hour. A tendency for the fish to descend (left to right in Figure 5) may be explained by their attraction to lights (automobile tail lights) located beside the ice shanty, before entering the beam. The light alone would not explain the unusual abundance because it was consistently used after dark. The fish could not be identified from the traces. However, rainbow smelt, stickleback (Pungitius pungitius) and minnows were observed near the surface and one each of rainbow smelt and burbot were collected the next day in overnight sets.

Behmer and Gleason (1975) concluded that fish moved mostly at dawn and during the late afternoon and at night in a similar study at one St. Marys River station. A diel pattern could not be established in the present study due to the low densities of the fish populations. Most of the fish were recorded between 2030 and 0030 hours and the balance between 1815 and 2330 hours.

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates were studied to establish baseline characteristics and determine potential effects of bubblers at this trophic level. The five stations will be treated separately to characterize each station. Although characterizations are done by groups in this text, data are presented by lower level taxa (Tables 11-16) to permit baseline and operational comparisons.

Station 1 was dominated by Chironomidae and Oligochaeta in the winter. The small number of organisms collected in October probably resulted from sampling on a hard substrate at the proposed site.

At Station 2 Chironomidae was dominant in the winter. Oligochaeta was the second most abundant group in the winter and dominant in October. Non-chironomid Insecta was relatively abundant all three months.

At Station 3, the dominant groups were Oligochaeta in October; Oligochaeta, Chironomidae and Ephemeroptera in February; and Mollusca and Chironomidae in March. One lamprey ammocoete was collected.

At Station 4, the differences between the high densities of Oligochaeta and Chironomidae in February, reduced numbers in March, and small samples in October are most likely related to differences in substrate along the bubbler sites. Pelecypoda were also an important constituent during the winter.

The abundance of Oligochaeta, Crustacea and other groups in October and small samples in the winter at Station 5 probably reflect a difference in substrate more than any other factor. None of the major groups appeared to be more abundant in this lacustrine environment than they were at the river stations.

Comprehensive studies of benthos in the St. Marys River (Hiltunen 1979, Poe et al. 1979) have demonstrated the extent of areal and temporal variation and a similar dominance of Chironomidae, Oligochaeta and Mollusca as in the present study. However, the present study augments the historical base by providing site specific information and describing the benthic components of the poorly-known navigation channel. The density of benthos in the navigation channel was clearly reduced in comparison with the St. Marys River littoral benthos community described in the literature.

PHYSICOCHEMICAL PARAMETERS

Physicochemical data are presented in Tables 17-19.

Water temperature was 34 F when open water sampling commenced on December 15, 1979. After mild weather, the water temperature was 32 F in late January when the ice cover became adequate for sampling through the ice.

Turbidity was highest in October, as expected, and declined to near the minimum detectable level during January and February. Secchi discs were generally visible on the bottom at depths up to 11 m in February and March. The differences among river stations were too small to account for any differences in the catch rate of fish. Effects of the ice breaker activity is not evident because sampling did not coincide with its passage on February 5 and 6 and March 12. However, turbidity remained low on March 15.

Dissolved oxygen remained near saturation throughout the study. Vertical and horizontal differences were too small to have a noticeable effect on the distribution of fish.

Velocity readings did not vary greatly among stations or over time at each station in comparison to the differences noted over the range of a single bubbler system. One exception was the relatively low velocity encountered in Whitefish Bay. Velocity at the stations was much higher than would be expected in shallower water and could be a factor in the depth distribution of the indigenous fauna.

DISCUSSION

Fishes of the St. Marys River have been surveyed in all seasons of the year. Since the distribution and abundance of fish exhibit great seasonal changes, only winter studies are useful to discuss possible effects of bubbler systems and winter navigation. Poe et al. (1979) found a dominance (77%) of white suckers in the littoral zone, followed by burbot, sculpin (Cottus), yellow perch (Perca flavescens), lake herring, northern pike, longnose sucker, and ninespine stickleback. They sampled primarily with fyke nets. A similar study by the U.S. Fish and Wildlife Service recorded northern pike, white sucker, walleye, burbot and yellow perch in hoop nets and gill nets (Wayne Crayton, pers. comm.). Gill net data for the present study generally confirm the existence of these species in the littoral zone and also demonstrate that the abundance of fish was much greater in the littoral zone than in the navigation channel. This trend is probably attributable to selection of habitat that maximizes the amount of cover and food available in the winter. The greater abundance of food in the littoral zone was evident from a comparison of benthos data collected in the present study and littoral benthos data of Poe et al. (1979) and Hiltunen (1979).

With the possible exception of velocity, the physicochemical parameters measured in the present study exhibited little spatial variation and could not have a noticeable effect on the winter depth distribution of aquatic organisms. Velocity may be an indirect factor because of its effects on the development and distribution of aquatic vegetation (cover) and the composition of the substrate.

Efficiency of fish sampling gear in the winter depends on specific characteristics of the gear as well as site-specific factors such as water depth, current, substrate, cover and extent of clogging by drifting macrophytes. High velocity and clogging resulted in the use of fyke nets instead of gill nets in certain littoral sites in the St. Marys River (Poe et al. 1979). In the present study, gill nets were more effective than fyke nets at bubbler sites. Because of the low density of fish at the bubbler sites and the apparent ability of fish to avoid nets in the extremely clear water, it was necessary to set a series of 46 m gill nets at angles to each other to guide the fish and provide an adequate catch for characterization of the fish community. Efficiency was futher increased by the use of small monofilament twine (110/3) in the gill nets. Set lines were more effective than gill nets for burbot.

Sonar studies were conducted to provide additional information on the temporal/diel variation in abundance of fish at river stations. Strip chart recordings demonstrated that fish were frequently absent from the area surveyed and that occasional mass movements along the edge of the navigation channel could be expected. Other habitats (outside of the bubbler sites) were not studied with sonar.

Sonar was the best technique of those employed to estimate densities of fish populations and determine diel variation and vertical distribution. However, recordings have

to be made frequently and throughout the diel period, in a heated shelter, to obtain definitive temporal/spatial distribution data. Concurrent sampling is needed to identify the dominant species.

Radio telemetry was the only technique used which provided information on the direction and speed of fish movement. Movement patterns varied greatly among the species and even among individuals of each species. Predominant winter movements were local, upsteam, or downstream. It is concluded that fish tracking is ot value to determine movements in relation to potential perturbations and to determine degree of mixing of populations within a water body in the winter. An intensive sampling program is needed so that relatively large and active individuals of the desired species can be selected.

For the circumstances under consideration (flowing water, suspended bubbler line, separated bubble columns), it can be concluded that the proposed bubbler systems would not have an adverse effect on the aquatic biota in the winter. Bubbler systems are often used to enhance water quality in the winter (Boyd 1979). Studies in the Duluth-Superior Harbor disclosed that bubblers increased dissolved oxygen and had no detrimental effects on water quality or macrobenthos (National Biocentric Inc. 1973, Swain et al. 1975, Sydor et al. 1974). A typical channel bubbler as illustrated by U.S. Army Engineer District, Detroit (1979) does not produce a continuous surface to bottom curtain and would not obstruct fish movement, even when oriented perpendicular to the direction of fish movement. Bubbler systems designed to exclude fish from power plant intakes were ineffective (Alevras 1973, Bainbridge 1964, Boreman 1977, Hanson et al. 1977, Lieberman and Muessig 1978, and Sonnichsen et al. 1973).

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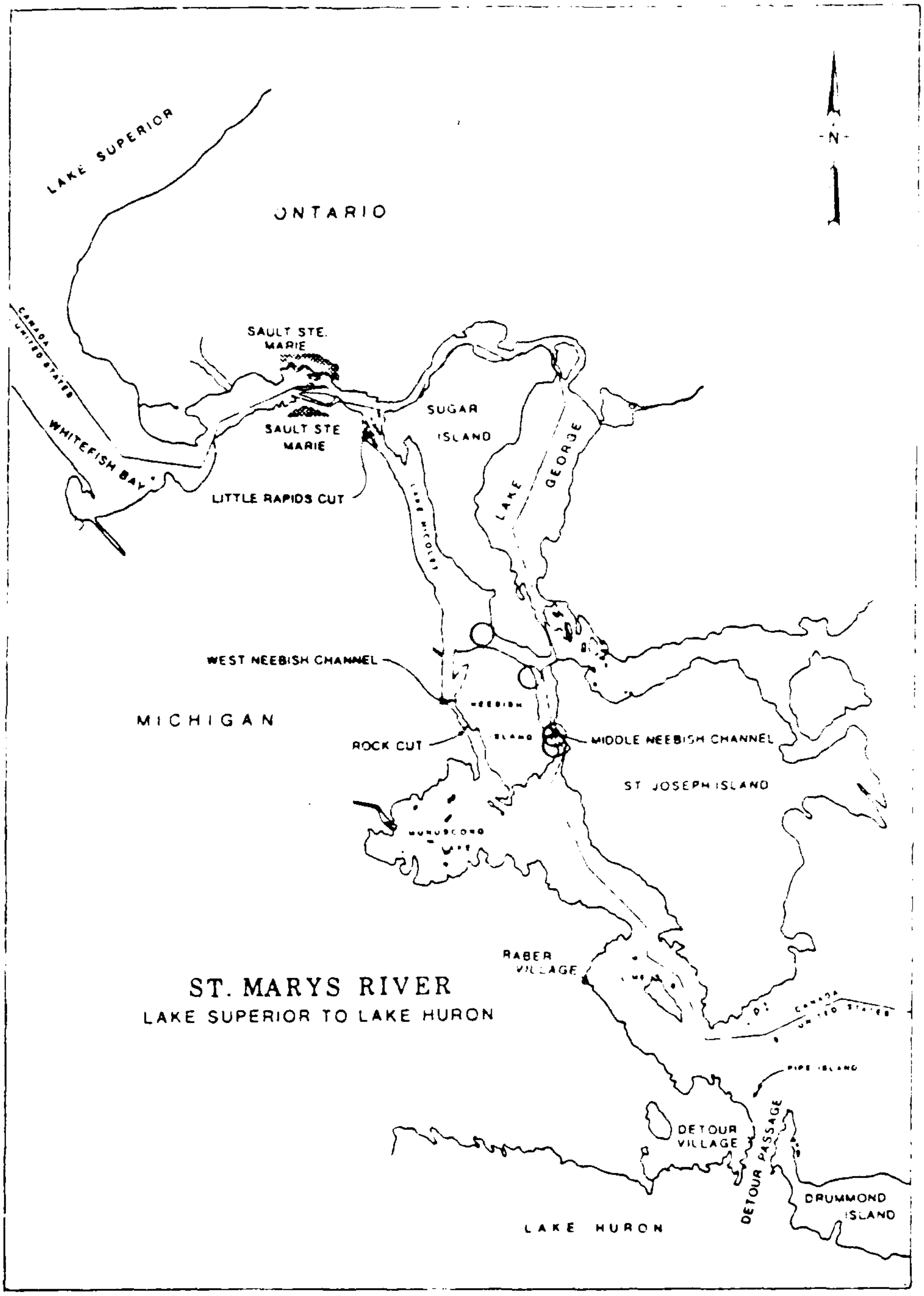


Figure 1. St. Marys River/Whitefish Bay study area. From U.S. Army Engineer District, Detroit (1979). River bubbler sites are circled.

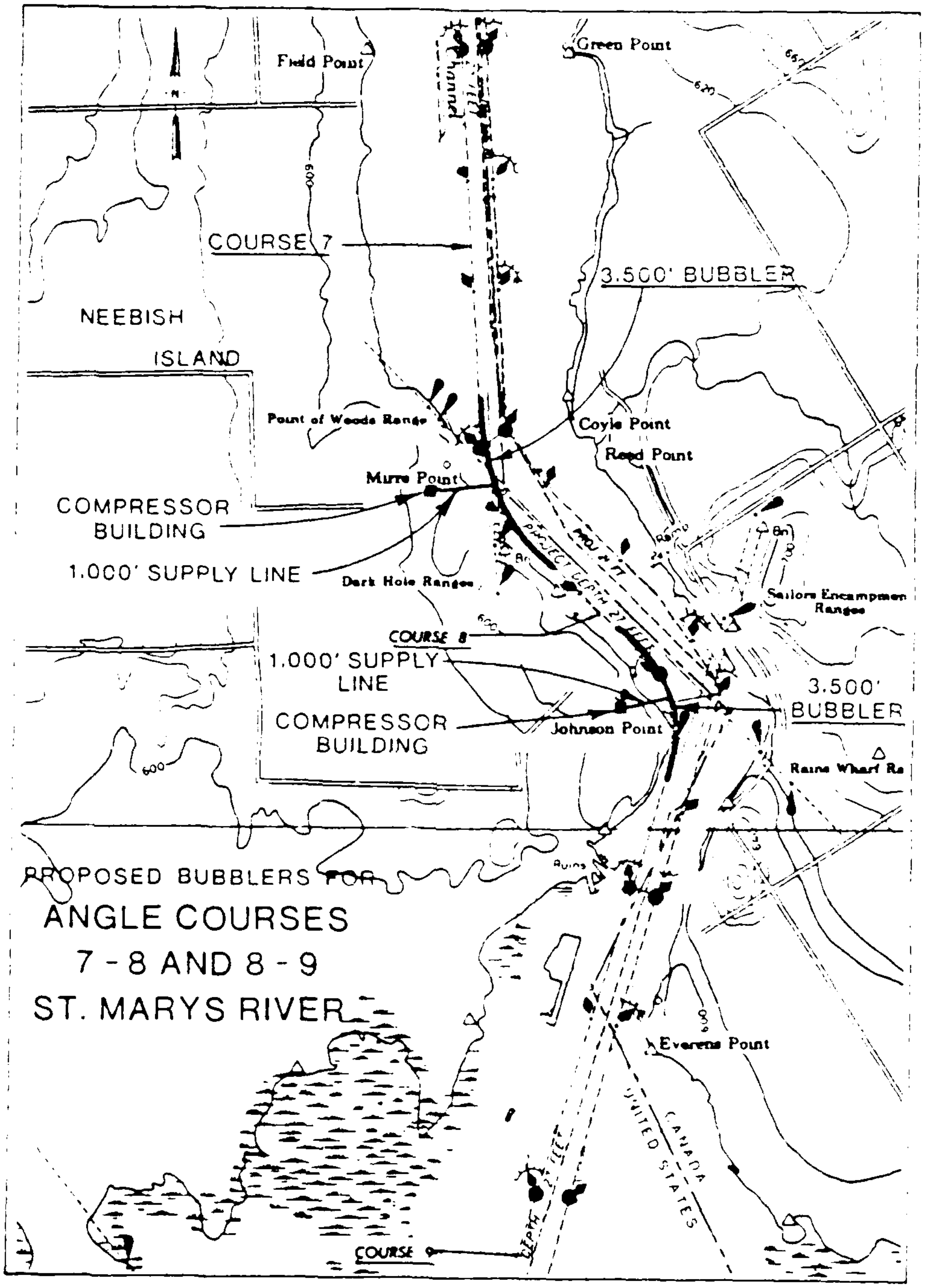


Figure 2. Locations of proposed bubbler sites and sampling stations in the lower segment of Middle Neebish Channel. Station 1 at Johnson Point and Station 2 at Mirre Point. From U.S. Army Engineer District, Detroit (1979).

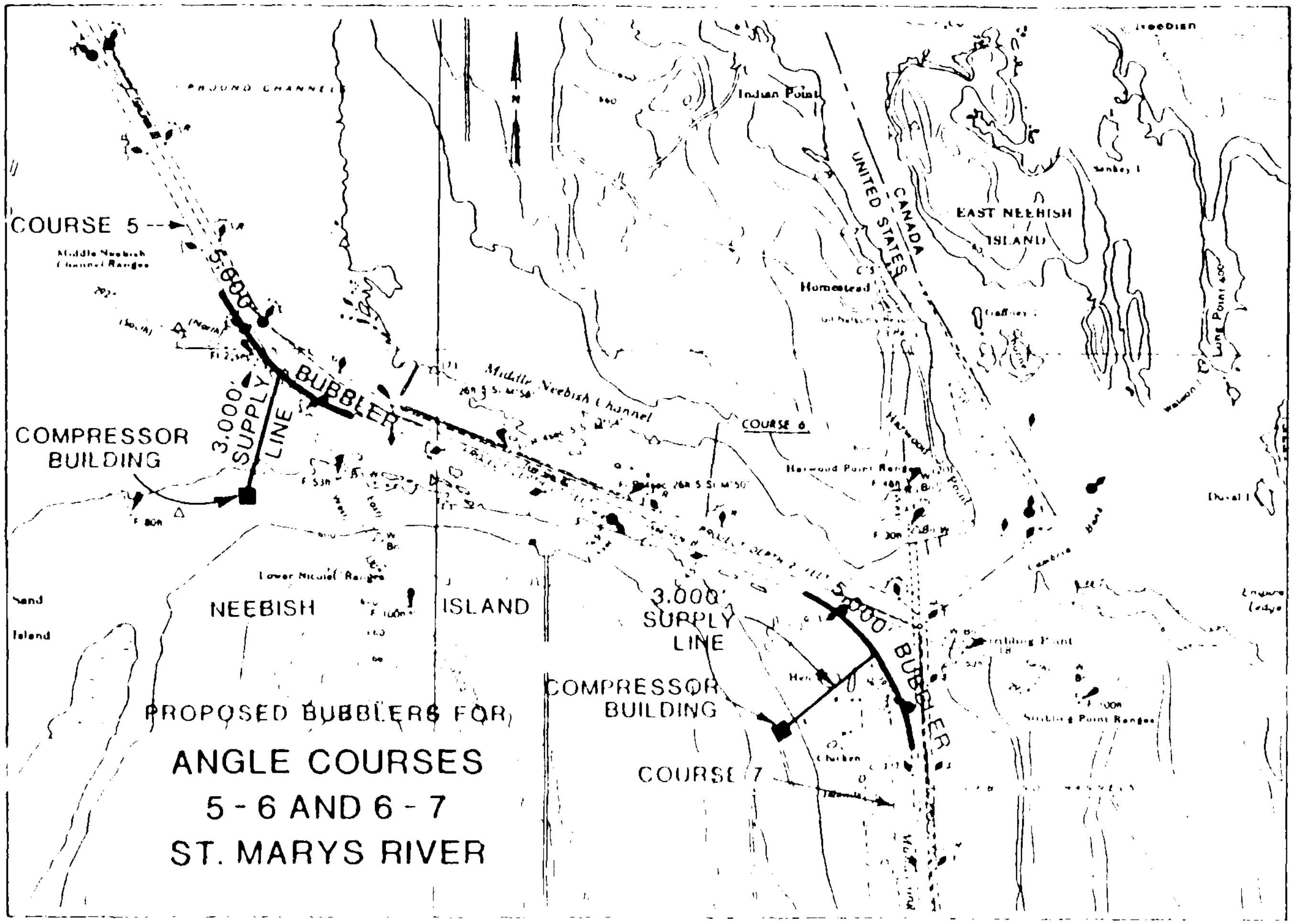


Figure 3. Locations of proposed bubbler sites and sampling stations north of Neebish Island. Station 3 at angle course 6-7 and Station 4 at angle course 5-6. From U.S. Army Engineer District, Detroit (1979).

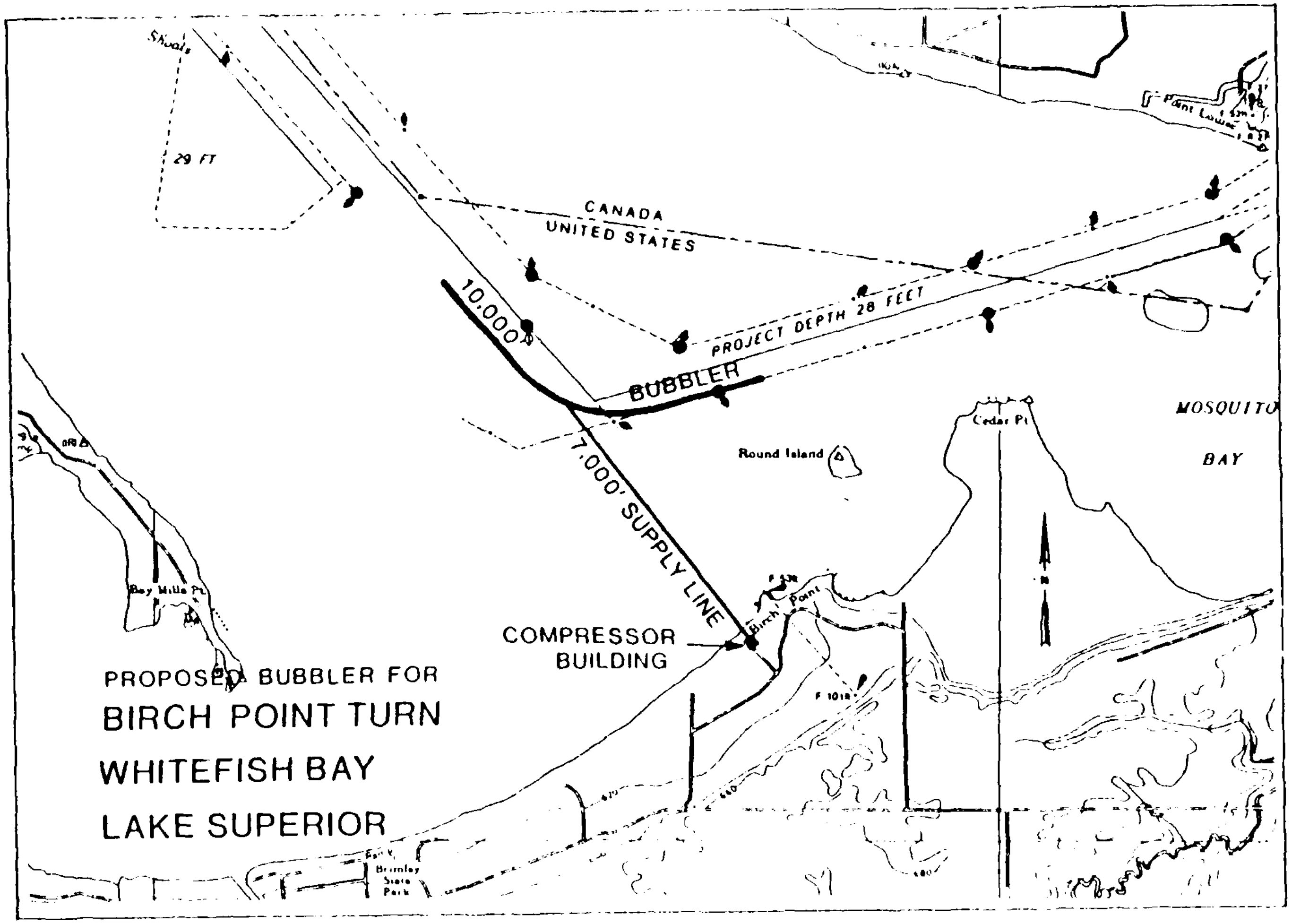


Figure 4. Location of proposed bubbler site and sampling area for Birch Point Turn, Whitefish Bay. From U.S. Army Engineer District, Detroit (1979).

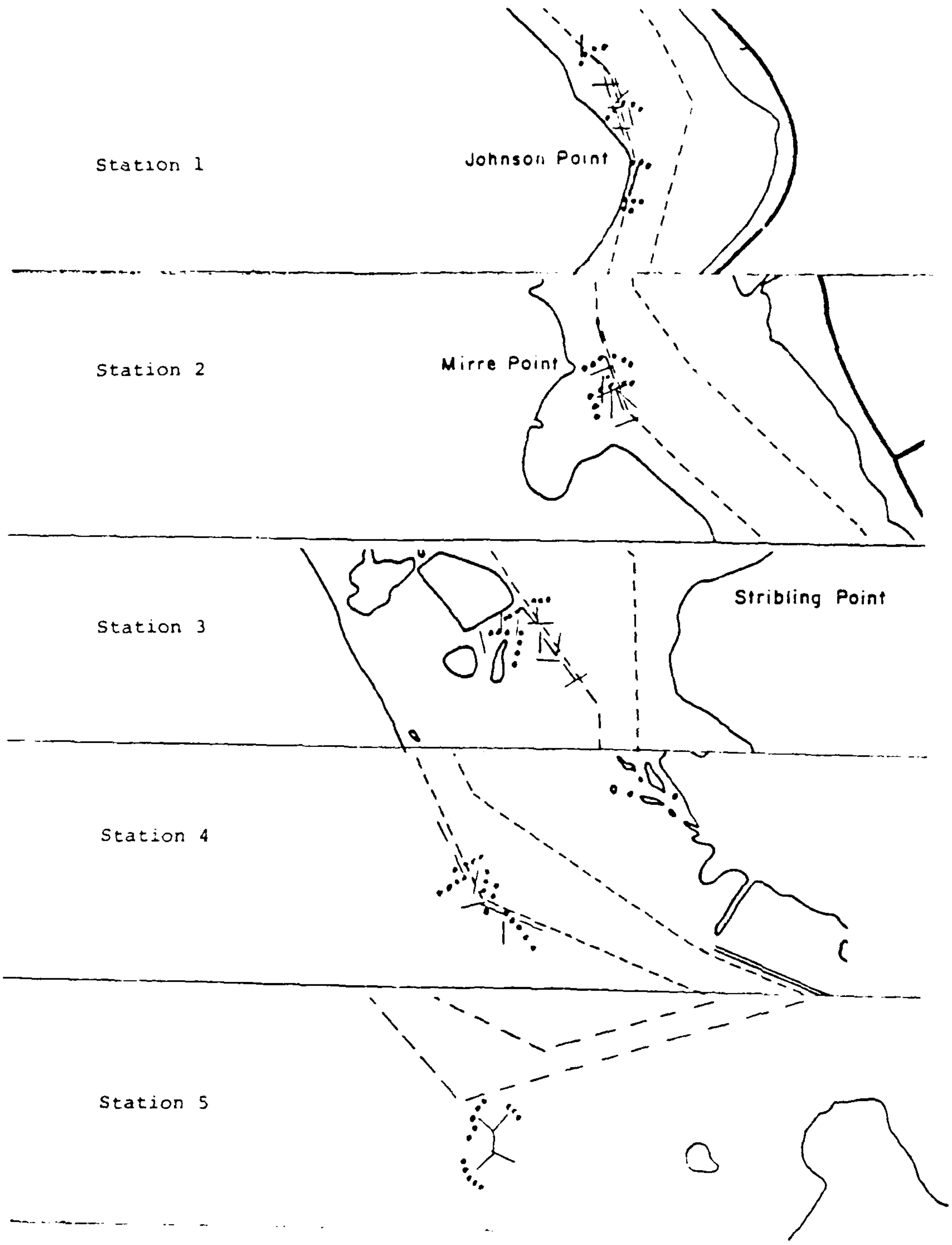


Figure 5. Locations of sampling points used for winter gill net (straight lines) and set line (dots) studies in St. Marys River (Stations 1-4) and Whitefish Bay (Station 5).

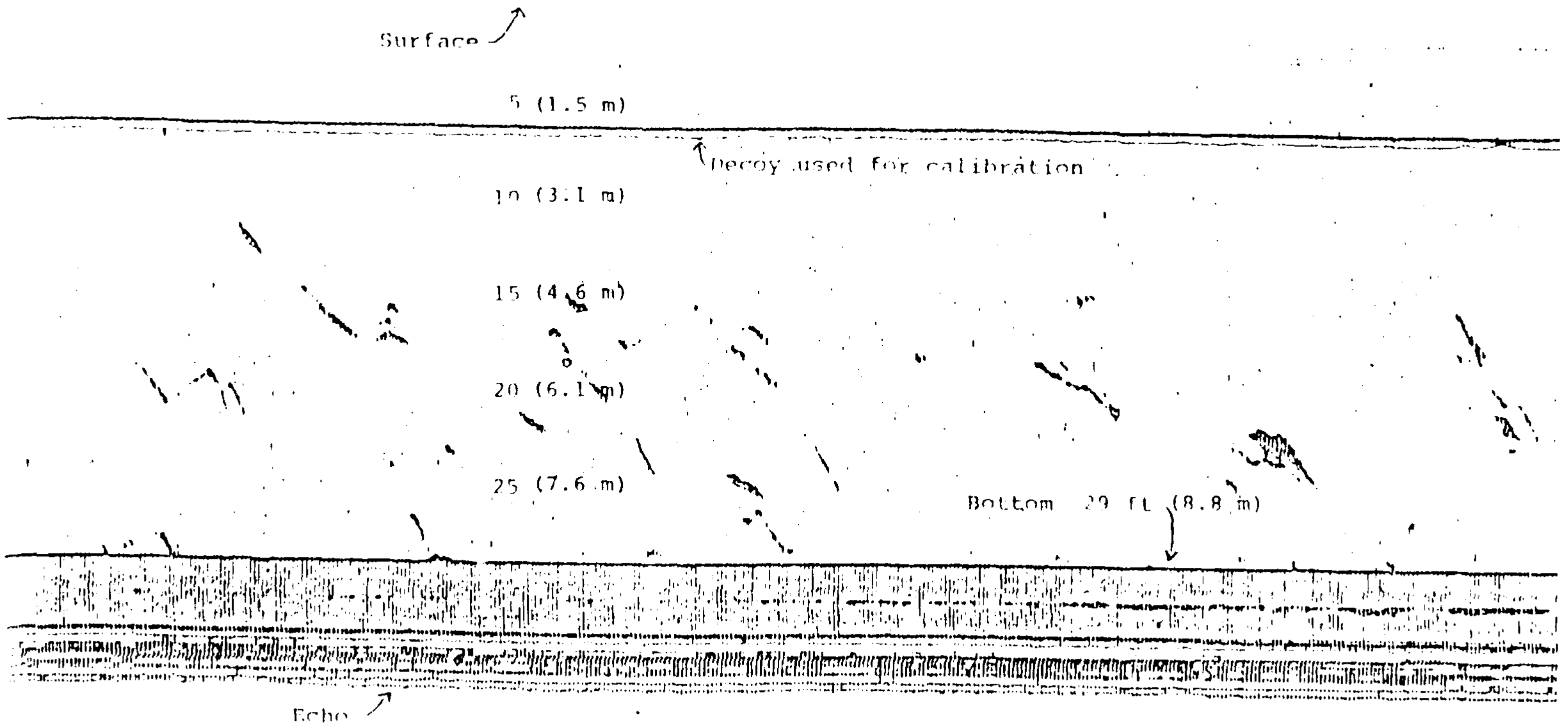


Figure 6. Traces of fish on strip chart from Ross Fine Line unit, Station 3, 4 March 1980, 2200 hours. Depth is given in feet (meters).

Table 1. Gill Net Data for Station 1 (Johnson Point), St. Marys River, 1979-1980. Number of Hours Fished and Number of Fish Given by Species and Mesh Size. Small Twine Size and Colored Nets (C) in Parentheses. Totals Exclude October Data. Exp. indicates experimental gill net.

Date	Species	Exp	25(1)	51(2)	76(3)	114(4½)	127(5)	Catch Rate
		Mesh Size in mm (in.)						
10-2 to 10-3		48						1 fish in 2 24-hr sets
	Rock bass	1						
12-15 to 12-16				24	24		24	No fish in 3 24-hr sets
	No fish							
12-28 to 1-2			48	24	144		48	4 fish in 11 24-hr sets
	Northern pike				3			
	Cisco				1			
1-25 to 1-30				120	96		120	3 fish in 14 24-hr sets
	Northern pike				1			
	Burbot						2	
2-11 to 2-22				144(C)	240	144(110/3)		3 fish in 16 24-hr sets, no fish in 2 48-hr sets and 1 fish in 1 96-hr set
	Longnose sucker				1			
	Burbot			1	1	1		
2-25 to 2-28						72(210/2C)		1 fish in 3 24-hr sets
	Northern pike					1		
3-12 to 3-17		240(C)	120	120(C)	120(C)			No fish in 5 24-hr sets and 4 fish in 5 72-hr sets
	Rainbow smelt		1					
	Longnose sucker	2			1			
3-18 to 3-21		72	72(C)			72(210/2C)		3 fish in [illegible] 24-hr sets and 4 fish in 5 48-hr sets
	Walleye					1		
						144(210/2)		
	Walleye					1		
	Burbot					2		
	Rainbow smelt		3					
Total Fish		2	4	1	8	6	2	
Total Days		13	10	18	26	18	8	
Fish/Day		0.15	0.40	0.06	0.31	0.33	0.25	

Table 2. Gill Net Data for Station 2 (Mirre Point), St. Marys River, 1979-1980. Number of Hours Fished and Number of Fish Given by Species and Mesh Size. Small Twine Size and Colored Nets (C) in Parentheses. Totals Exclude October Data

Date	Species	Exp.	25(1)	51(2)	76(3)	114(4½)	127(5)	Catch Rate
			Mesh Size in mm (in.)					
10-2 to 10-3		48						3 fish in 2 24-hr sets
	Walleye	3						
12-15 to 12-16				24	24			No fish in 2 24-hr sets
12-28 to 1-2		24		72	72	24(110/3)	72	2 fish in 11 24-hr sets
	Cisco				1			
	Northern pike	1						
1-23 to 1-31				72	192	120	168	8 fish in 17 24-hr sets and 1 fish in 3 48-hr sets
	Northern pike				2			
	Burbot					1	6	
2-11 to 2-22				264(C)	240(C)		240(C)	1 fish in 12 24-hr sets and 2 fish in 3 96-hr sets
	Burbot				1			
	Cisco			2				
2-25 to 3-1		72(C)			48(210/2C)	144(110/3)		4 fish in 11 24-hr sets
	Burbot	1				1		
	Rainbow smelt	1						
	White sucker					1		
3-12 to 3-17			120(C)	120(C)	120		120(C)	1 fish in 4 48-hr sets and 3 fish in 4 72-hr sets
	Cisco				1			
	Northern pike				1			
	Rainbow smelt		2					
3-18 to 3-21		72(C)			72(210/2C)	72(210/2C)		No fish in 4 24 sets and 2 fish in 4 48-hr sets
	Whitefish					1		
	Cisco					1		
						72(210/2)		
Total Fish		3	2	2	5	5	2	
Total Days		7	5	23	32	18	25	
Fish/Day		0.43	0.40	0.09	0.16	0.28	0.28	

Table 3. Gill Net Data for Station 3 (Angle Course Turn 6-7), St. Marys River, 1979-1980. Number of Hours Fished and Number of Fish Given by Species and Mesh Size. Small Twine Size and Colored Nets (C) in Parentheses. Totals Exclude October Data and Shallow Water Sets.

		Mesh Size in mm (in.)						
Date	Species	Exp	25(1)	51(2")	76(3")	114(4½")	127(5")	Catch Rate
10-2 to 10-3		48						1 fish in 2 24-hr sets
	Northern pike	1				3		
12-28 to 1-2				72	72	24(110/2)	72	5 fish in 10 24-hr sets
	Cisco				1	1		
	Whitefish					1		
	White sucker					1		
	Burbot					1		
12-31 to 1-2[a] (Shallow)		48						13 fish in 2 24-hr sets
	Northern pike	4						
	Yellow perch	2						
	White sucker	7						
1-26 to 2-2		96		120[b]	120	96(110/3)		15 fish in 16 24-hr sets and no fish in 1 48-hr set
	Cisco			5		1		
	Whitefish				1			
	Burbot				2	2		
	White sucker					2		
	Rainbow smelt	2						
2-13 to 2-16[c]		72				72(110/3)		5 fish in 3 24-hr sets
	Burbot					3		
	Northern pike					1		
	White sucker	1						
						72(210/2)[c]		
2-18 to 2-22				96(C)	96(210/2)	96(110/3)		10 f[illegible]n 12 24-hr sets
	Northern pike				1	2		
	White sucker				1	1		
	Yellow perch					1		
	Burbot					1		
	Cisco					2		
	Walleye					1		

(Continued)

Table 3 (Continued)

Date	Species	Mesh Size in mm (in.) Exp	25(1")	51(2")	76(3")	114(4½")	127(5")	Catch Rate
2-20 to 2-22[d] (Shallow)						48(210/2)		9 fish in 2 24-hr sets
	Northern pike					1		
	White sucker					4		
	Cisco					4		
2-25 to 2-27 (Shallow)						48(110/3)		10 fish in 2 24-hr sets
	Cisco					5		
	White sucker					4		
	Yellow perch					1		
2-25 to 2-27					48(210/2)	48(210/2C)		17 fish in 8 24-hr sets
	Cisco				5[c]	2		
	Whitefish					1		
	White sucker				1			
						48(110/3)		
	Cisco					1		
	Whitefish					2		
	Northern pike					1		
						48(110/3)		
	Cisco					3		
	White sucker					1		
3-4 to 3-5			24[e]			24(110/3)[e]		1 fish in 2 24-hr sets
	Rainbow smelt		1					
3-12 to 3-15			72		72(210/2C)	72(110/3)		9 fish in 3 72-hr sets and no fish in 1 48-hr set and no fish in 1 24-hr set
	Cisco				1	1		
	Northern pike				2	2		
	Rainbow smelt		3					
						72(110/3)		
3-15 to 3-17					48(210/2)	144(210/2)		5 fish in 4 48-hr sets
	White sucker				1	2		
	Burbot					1		
	Whitefish					1		

(Continued)

Table 3 (Concluded)

Date	Species	Exp	25(1")	51(2")	76(3")	114(4½")	127(5")	Catch Rate
		Mesh Size in mm (in.)						
3-18 to 3-21					72	144(110/3)		3 fish in 3 24-hr sets and 3 fish in 3 48-hr sets
	Cisco				3			
	Rainbow trout					1		
	Northern pike					2		
3-18 to 3-21[f] (Shallow)			72(C)		96(210/2C)			23 fish in 3 24-hr sets
	Rainbow smelt		13					
	Yellow perch		1		2			
	Trout-perch		1					
	Cisco				20			
	Rock bass				1			
	Northern pike				2			
	White sucker				1			
Total Fish		3	4	5	19	42	0	
Total Days		7	4	9	22	40	3	
Fish/Day		0.43	1.00	0.56	0.86	1.05	0	

[a] Set in shallow water (24-4.6 m). Yellow perch in 51 mm mesh. Northern pike and white sucker in 114 mm mesh.
[b] Set between 2.4 m and 7.6 m depth contours. Two yellow perch and one cisco captured at 3.7 m not included.
[c] No fish in second 114 mm net with 210/2 twine (72 hr). Three nets stolen.
[d] Set in shallow water (3.1 m)
[e] 1.8 m wide net set vertically.
[f] 25 mm mesh at 3.1-10.1 m. 76 mm mesh at 2.4 m.

Table 4. Gill Net Data for Station 4 (Angle Course Turn 5-6), St. Marys River, 1979-1980. Number of Hours Fished and Number of Fish Given by Species and Mesh Size. Small Twine Size and Colored Nets (C) in Parentheses. Totals Exclude October Data and Shallow Water Sets.

Date	Species	Mesh Size in mm (in.) Exp	51(2")	76(3")	114(4½")	127(5")	Catch Rate
10-2 to 10-3		48					1 fish in 2 48-.
	White sucker	1					
12-30 to 1-2			48	120		48	7 fish in 9 24-hr sets
	Northern pike		1	3			
	Brook trout		1				
	Cisco		1				
	Burbot					1	
2-4 to 2-8				120		120	4 fish in 8 24-hr sets
	Burbot					3	
	Longnose sucker			1			
2-4 to 2-8[a] (Shallow)		120			120(110/3)		
	Northern pike				2		
	Splake				1		
	Whitefish				3		
	Longnose sucker	1			2		
	White sucker				2		
	Burbot				6		
2-19 to 2-22[b]				72(210/2C)	72(210/2		9 fish in 9 24-hr sets
	Longnose sucker				5		
	Burbot			1			
					72(110/3)		
	Rainbow trout				1		
	Longnose sucker				2		
3-10 to 3-17				168(210/2C)	144(110/3)		3 fish in 5 48-hr sets and no fish in 1 24-hr set
	Burbot				2		

Table 4 (Continued)

Date	Species	Mesh Size in mm (in.) Exp	51(2")	76(3")	114(4½")	127(5")	Catch Rate
3-10 to 3-17[c] (Shallow)		72C			120(210/2C)		No fish in 2 24-hr sets and 1 fish in 3 48-hr sets
	Burbot				1		
3-18 to 3-21				72(C)	72(110/3)		1 fish in 6 24-hr sets
	Northern pike				1		
3-18 to 3-21[d] (Shallow)			72C			72C	No fish in 6 24-hr sets
Total Fish		0	3	6	11	4	
Total Days		8	2	23	15	7	
Fish/Day		0	1.50	0.26	0.73	0.57	

[a] 114 m mesh at 3.4-9.8 m. Experimental net at 3.7 m.

[b] One shallow (3.1 m) set data (114 mm, 210/2 mesh, no fish in 48-hr) not included.

[c] Experimental net at 3.7 m. 114 mm mesh at 3.4-7.3 m.

[d] 51 mm mesh at 3.7 m. 127 mm mesh at 3.4-7.3 m.

Table 5. Gill Net Data for Station 5 (Birch Point Turn),
Whitefish Bay, Lake Superior, 1980.
Number of Hours Fished and Number of
Fish Given by Species and Mesh Size.
Small Twine Size and Colored Nets (C)
in Parentheses.

Date	Species	Mesh Size in mm (in.) Exp.	25(1")	76(3")	114(4½")
3-2 to 3-8		96(C)	144(C)	192(210/2C)	240(110/3)
	Rainbow smelt	1	21		
	Northern pike			5	12
	White sucker				3
	Burbot				1
	Cisco			1	
					48(210/2)
Total Fish		1	21	6	16
Total Days		4	6	8	12
Fish/Day		0.25	3.50	0.75	1.33

Table 6. Numbers of Fish Caught in Gill Nets in St. Marys River (Stations 1-4) and Whitefish Bay (Station 5), Excluding Shallow Sets (Stations 3 and 4), December 1979-March 1980.

Species	Station 1	Station 2	Station 3	Station 4	Station 5	Total
Cisco	1	5	26	1	1	34
Lake whitefish		1	6			7
Rainbow smelt	4	3	6		22	35
Northern pike	5	4	11	5	17	42
Brook trout				1		1
Rainbow trout			1	1		2
Longnose sucker	4			8		12
White sucker		1	11		3	15
Burbot	7	10	10	8	1	36
Yellow perch			1			1
Walleye	2		1			3
Total Fish	23	24	73	24	44	188
Total Net Days	93	110	88	55	30	376
CPE	0.25	0.22	0.83	0.44	1.47	0.64

Table 7. Hoop Net and Fyke Net Data for St. Marys River Stations, 1979-1980. Number of Hours Fished and Number of Fish Caught Listed by Station.

Date, depth, and Net Type	Species	Stations 1	2	3
10-5 (6.1 m)		24	24	
Hoop	Smallmouth bass	7		
	Rock bass	5	9	
10-5 (3.7-5.5 m)		24	24	
Fyke	Smallmouth bass	2		
	Rock bass	3	33	
12-29 to 1-1 (6.4 m)			96	
Fyke	No fish		0	
12-31 to 1-1 (3.4 m)				48
Fyke	No fish			0
3-8 to 3-21[a] (9.2 m)				312
Fyke	No fish			0

[a]Tended 3-15 and 3-21

Table 8. Number of 24-hr Sets, Burbot Caught, and CPE for Set Lines Baited with Frozen Smelt at Stations 1-5, St. Marys River and Whitefish Bay, 1980.

Date	Station 1			Station 2			Station 3			Station 4			Station 5		
	Sets	Fish	CPE	Sets	Fish	CPE	Sets	Fish	CPE	Sets	Fish	CPE	Sets	Fish	CPE
1-24 to 1-30	30	10	0.33	30	11	0.37	48	16	0.33						
2-5 to 2-8										45	8	0.18			
2-12 to 2-16	24	12	0.50	24	3	0.13	21	10	0.48						
2-25 to 2-28	27	13	0.48	30	11	0.37	20	9	0.45						
3-2 to 3-8													42	7	0.17
3-16 to 3-21	24	5	0.21	24	2	0.08	24	9	0.38	36	7	0.19			
Total	105	40	0.38	108	27	0.24	113	44	0.41	81	15	0.19	42	7	0.17

Table 9. Telemetry Data for Fish Tagged and Located in the St. Marys River, 1980. Included are Tag Frequencies, Release Dates (X), Kilometers Moved Between Survey Dates, and Primary Direction of Movement (U-Upstream, D-Downstream, E-East, W-West).

		Dates of Release and Field Surveys													Distance			Overall
		February					March								Recorded	Days	Minimum	Movement
Species	Tag	21	22	26	27	28	5	8	15	17	18	19	23	24	(km)	at Large	m/Day	Pattern
Burbot	056			X	1.0U			2.3U	0.8U					0.6D	4.7	27	174	U
	175				X			0						0.6U	0.6	26	23	Local
	474			X				2.0U	3.1U					0.3D	5.4	27	200	U
	073										X			0.3E	0.3	6	50	Local
	093										X			4.7D	4.7	6	783	D
	133										X			3.2D	3.2	6	533	D
	212										X		0.3U	0.2E	0.5	6	83	Local
	434											X		0.2D	0.2	5	40	Local
White sucker	414	X		0.5U										0.8D	1.3	32	40	Local
	372	X	O					0.1U	2.1D					4.5D	6.7	32	209	D
	252			X										3.5D	3.5	27	130	D
	514				X	0.2D	0.3W	0.5D	0.1D					0.7U	1.8	26	69	Local
	274				X		2.3D	O	O					0.8D	3.1	26	119	D
Longnose sucker	114									X				0.3E	0.3	7	43	Local
Northern pike	233		X	0.2W	O	O	0.2W	0.4E	0.5U				0.5W	0.5U	2.3	31	74	Local
	332											X	0.6W	1.3E	1.9	5	380	E
	154											X	0.4W	0.6U	1.0	5	200	U
Whitefish	396									X			0.5W	3.6D	4.1	7	586	D
Walleye	312		X											-	-	-	-	

Table 10. Sonar Data for Stations 1-4, St. Marys River, February and March, 1980

Date	Station	Time	Number of Fish	Fish per Hour
2-2	2	1615-1715	0	
2-4	4	620-800	0	
2-5	4	1200-1420	0	
2-5	4	1650-1745	0	
2-12	3	1815-2015	2	1.0
2-13	2	600-830	0	
2-13	2	1805-1845	0	
2-13	2	1900-2000	1	1.0
2-14	1	600-830	0	
2-14	1	1700-2000	0	
2-15	3	600-800	0	
2-15	3	1715-2000	0	
2-25	2	1915-2000	0	
2-25	2	2030-2100	0	
3-4	3	2030-0030	325	81.3
3-5	2	1820-2100	0	
3-6	1	1800-1900	0	
3-6	1	2100-2330	17	4.3
3-7	4	1840-2140	1	0.3
3-13	2	1440-1640	0	

Table 11. Mean Densities of Zoobenthic Macroinvertebrates in Ponar Grab Samples Collected at Station 1 from the St. Marys River, 1979-1980.

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Cnidaria			
Hydra			191
Nematoda		184	99
Mollusca			
Amnicola			7
Pisidium		158	33
Sphaerium	27	26	39
Annelida			
Oligochaeta	72	422	382
Arachnoidea			
Acari		7	
Crustacea			
Cladocera	415		
Copepoda	40	26	
Isopoda		7	
Asellus			7
Ephemeroptera			
Ephemera			46
Hexagenia limbata		7	46
Trichoptera			13
Neureclipsis			7
Hydropsyche			7
Cheumatopsyche			13
Ceraclea		13	39
Neuroptera			
Sisyra			7
Diptera			
Ceratopogonidae		39	39
Chironomidae			
Procladius			7
Larsia		7	
Thienemannimyia			26
Orthocladiinae		20	33
Heterotrissocladius		46	66
Parakiefferiella		916	606
Trissocladius			7
Demicryptochironomus			13
Endochironomus			7
Hydrobaenus		26	46
Polypedilum			39
Zenochironomus	73		

(Continued)

Table 11. (Concluded)

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Empididae	13		46
Total Gastropoda			7
Total Pelecypoda	37	184	72
Total Oligochaeta	72	422	382
Total Crustacea	455	33	7
Total Non-Chironomid Insecta	13	59	263
Total Chironomidae	73	1015	850
Total Others		191	290
Total Benthos	640	1904	1871

Table 12. Mean Densities of Zoobenthic Macroinvertebrates in Ponar Grab Samples Collected at Station 2 from the St. Marys River, 1979-1980.

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Cnidaria			
Hydra	7		
Nematoda	66	158	395
Nemertea		13	
Mollusca			
Amnicola		26	
Valvatidae	40		
Valvata sincera		7	
Valvata tricarinata		7	
Pisidium	125	204	257
Sphaerium	105	59	46
Anodontinae	7		7
Lampsilis		7	
Annelida			
Oligochaeta	1258	1284	836
Arachnoidea			
Acari		13	20
Crustacea			
Cladocera	53	20	
Copepoda	7	73	13
Hyalella azteca			7
Lirceus			7
Ephemeroptera	7		
Ephemeridae		7	
Caenis			7
Ephemera		46	13
Hexagenia limbata	408	53	39
Hemiptera			
Corixidae	20		
Megaloptera			
Sialis	13	20	7
Trichoptera			
Cheumatopsyche			13
Ceraclea	20		
Oecetis	7		7
Polycentropus		7	
Diptera			
Ceratopogonidae	198	369	389
Chironomidae			
Procladius	85	26	20
Ablabesmyia	7	13	7
Larsia		40	46

(Continued)

Table 12. (Concluded)

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Thienemannimyia			7
Potthastia	7		13
Monodiamesa	26	13	32
Epoicocladius		13	13
Heterotrissocladius		237	72
Orthocladius		7	79
Parakiefferiella		494	184
Pseudosmittia			13
Chironomus		7	
Cryptochironomus			7
Demicryptochironomus	7	263	27
Pagastiella		66	59
Paracladopelma			13
Tribelos			7
Polypedilum		270	297
Stictochironomus	7	263	13
Tanytarsini		7	910
Cladotanytarsus		7	
Tanytarsus		39	
Total Gastropoda	40	40	
Total Pelecypoda	237	270	310
Total Oligochaeta	1258	1284	836
Total Crustacea	60	93	27
Total Non-Chironomid Insecta	700	502	475
Total Chironomidae	139	1765	1820
Total Others	73	184	415
Total Benthos	2507	4138	3884

Table 13. Mean Densities of Zoobenthic Macroinvertebrates in Ponar Grab Samples Collected at Station 3 from the St. Marys River, 1979-1980.

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Nematoda	66	26	
Nemertea	7		
Mollusca			
Amnicola		33	
Valvata sincera		20	
Pisidium	408	165	277
Sphaerium	46	13	7
Unionidae			13
Annelida			
Oligochaeta	1528	474	
Arachnoidea			
Acari		7	
Crustacea			
Cladocera	13		26
Copepoda	33	7	7
Ostracoda	7		
Hyalella azteca		13	
Lirceus		39	
Ephemeroptera			
Caenis	7		
Ephemera	102		
Hexagenia limbata	13	402	53
Coleoptera			
Haliplus		7	
Trichoptera			
Phylocentropus			13
Diptera			
Ceratopogonidae	72	138	145
Procladius	20	20	20
Ablabesmyia		20	7
Larsia	7	13	46
Thienemannimyia			7
Potthastia	20		13
Monodiamesa	30	20	33
Epoicocladius		7	33
Heterotrissocladius		46	
Parakiefferiella		85	86
Cryptochironomus	27		
Demicryptochironomus	27	66	33
Pagastiella		13	26
Paracladopelma		20	

(Continued)

Table 13. (Concluded)

Taxa	October 5, 1979 no./m^2	February 18, 1980 no./m^2	March 20, 1980 no./m^2
Polypedilum	323	13	53
Cladotanytarsus			7
Tanytarsus		7	
Petromyzontidae			
Ammocoete			7
Total Gastropoda		53	
Total Pelecypoda	454	178	297
Total Oligochaeta	1528	474	
Total Crustacea	53	59	33
Total Non-Chironomid Insecta	85	656	211
Total Chironomidae	454	330	364
Total Others	73	33	7
Total Benthos	2657	1783	912

Table 14. Mean Densities of Zoobenthic Macroinvertebrates in Ponar Grab Samples Collected at Station 4 from the St. Marys River, 1979-1980.

Taxa	October 5, 1979 no./m²	February 5, 1980 no./m²	March 20, 1980 no./m²
Cnidaria			
Hydra	13		
Nematoda		296	92
Mollusca			
Amnicola		33	13
Valvata sincera		33	
Valvata tricarinata		7	39
Pisidium		375	231
Sphaerium	7	99	86
Annelida			
Hirudinea	7		
Oligochaeta	13	2049	356
Arachnoidea			
Acari		53	26
Crustacea			
Cladocera	270	7	20
Copepoda		7	
Hyalella azteca			20
Ephemeroptera			
Ephemera		26	13
Hexagenia limbata		99	72
Trichoptera			
Oecetis			7
Diptera			
Ceratopogonidae		165	92
Chironomidae			
Procladius		211	59
Larsia		230	99
Potthastia		7	
Monodiamesa		46	53
Cricotopus		7	
Hetertrissocladius		13	53
Nanocladius			7
Orthocladiinae			13
Parakiefferiella		692	435
Chironomini			7
Cryptochironomus		26	7
Demicryptochironomus		27	59
Endochironomus		7	
Harnischia		7	
Cryptotendipes		7	
Pagastiella		13	

(Continued)

Table 14. (Concluded)

Taxa	October 5, 1979 no./m^2	February 5, 1980 no./m^2	March 20, 1980 no./m^2
Paracladopelma		7	13
Polypedilum		402	99
Cladotanytarsus	7		
Tanytarsus		13	
Total Gastropoda		73	52
Total Pelecypoda	7	474	317
Total Oligochaeta	13	2049	356
Total Crustacea	270	14	40
Total Non-Chironomid Insecta	0	290	184
Total Chironomidae	7	1715	904
Total Others	20	349	118
Total Benthos	317	4964	1971

Table 15. Mean Densities of Zoobenthic Macroinvertebrates in Ponar Grab Samples Collected at Station 5, Whitefish Bay, 1979-1980.

Taxa	October 5, 1979 no./m^2	March 4, 1980 no./m^2
Nematoda	316	
Nemertea		7
Mollusca		
Lymnaeidae	13	
Planorbidae	7	
Amnicola	184	
Valvata sincera	244	7
Valvata tricarinata	53	
Pisidium	277	26
Sphaerium	59	
Annelida	20	
Hirudinea	26	
Oligochaeta	1390	46
Arachnoidea		
Acari	7	
Crustacea		
Cladocera	883	13
Copepoda	66	46
Ostracoda	66	
Hyalella azteca	125	
Lirceus	184	
Ephemeroptera		
Stenonema	7	
Hexagenia limbata	7	
Trichoptera		
Limnephilidae	7	
Ceraclea	7	
Diptera		
Chironomidae		
Procladius	20	
Larsia	7	
Potthastia	13	
Monodiamesa	26	13
Orthocladiinae	20	7
Cricotopus	13	
Heterotrissocladius	7	264
Parakiefferiella	26	66
Cryptochironomus	125	33
Demicryptochironomus	33	7
Dicrotendipes	13	

(Continued)

Table 15. (Concluded)

Taxa	October 5, 1979 no./m^2	March 4, 1980 no./m^2
Saetheria	13	
Paracladopelma		7
Paralauterborniella	26	
Polypedilum	86	
Pseudochironomus	92	7
Stictochironomus	13	7
Tanytarsini	7	
Cladotanytarsus	86	7
Tanytarsus	118	7
Total Gastropoda	501	7
Total Pelecypoda	336	26
Total Oligochaeta	1390	46
Total Crustacea	1324	59
Total Non-Chironomid Insecta	28	
Total Chironomidae	744	425
Total Others	369	7
Total Benthos	4692	570

Table 16. Species List of Zoobenthic Organisms Collected from the St. Marys River and Whitefish Bay, Michigan, 1979-1980

Cnidaria
  Hydrozoa
    Hydroida
      Hydridae
          Hydra

Nemertea

Nematoda

Mollusca
  Gastropoda
    Mesogastropoda
      Hydrobiidae
          Amnicola
      Valvatidae
          Valvata sincera
          Valvata tricarinata
    Basommatophora
      Lymnaeidae
      Planorbidae
  Pelecypoda
    Eulamellibranchia
      Unionidae
        Anodontinae
        Lampsilinae
          Lampsilis
      Sphaeriidae
          Pisidium
          Sphaerium

Annelida
  Hirudinea
  Oligochaeta

Arthropoda
  Arachnoidea
      Acari
  Crustacea
    Cladocera
    Copepoda
    Ostracoda
    Amphipoda
      Talitridae
          Hyalella azteca

(Continued)

Table 16. (Continued)

- Isopoda
  - Asellidae
    - *Asellus*
    - *Lirceus*
- Insecta
  - Ephemeroptera
    - Ephemeridae
      - *Ephemera*
      - *Hexagenia limbata*
    - Caenidae
      - *Caenis*
    - Heptageniidae
      - *Stenonema*
  - Hemiptera
    - Corixidae
  - Megaloptera
    - Sialidae
      - *Sialis*
  - Neuroptera
    - *Sisyra*
  - Trichoptera
    - Polycentropodidae
      - *Neureclipsis*
      - *Polycentropus*
      - *Phylocentropus*
    - Hydropsychidae
      - *Cheumatopsyche*
      - *Hydropsyche*
    - Limnephilidae
      - Limnephilinae
    - Leptoceridae
      - *Ceraclea*
      - *Oecetis*
  - Diptera
    - Ceratopogonidae
    - Chironomidae
      - Tanypodinae
        - *Procladius*
        - *Ablabesmyia*
        - *Larsia*
        - *Thienemannimyia*
      - Diamesinae
        - *Potthastia*
        - *Monodiamesa*
      - Orthocladiinae
        - *Cricotopus*
        - *Epoicocladius*
        - *Heterotrissocladius*

(Continued)

Table 16. (Concluded)

Nanocladius
Orthocladius
Parakiefferiella
Pseudosmittia
Trissocladius
Chironominae
Chironomus
Cryptochironomus
Demicryptochironomus
Dicrotendipes
Endochironomus
Saetheria
Hydrobaenus
Pagastiella
Paracladopelma
Paralauterborniella
Tribelos
Polypedilum
Pseudochironomus
Stictochironomus
Xenochironomus
Cladotanytarsus
Tanytarsus
Empididae

Chordata
Agnatha
Petromyzontiformes
Petromyzontidae

Table 17. Water Temperature Data (^{o}F) at Surface (S), Middle (M) and Bottom (B) for Air Bubbler Study, St. Marys River and Whitefish Bay, Michigan

Date	1			2			3			4			5		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
10-2-79	61	-	-	61	-	-	61	-	-	61	-	-	-	-	-
10-5, 6-79	59	-	-	59	-	-	59	-	-	59	-	-	58	-	-
12-15-79	34	34	34	34	34	34	34	-	-	-	-	-	-	-	-
12-29, 31-79	39	39	39	39	39	39	39	39	39	39	39	39	-	-	-
1-31-80	-	-	-	32	32	32	-	-	-	-	-	-	-	-	-
2-2, 5-80	-	-	-	-	-	-	32	32	32	32	32	32	-	-	-
2-15-80	32	32	32	32	32	32	32	32	32	-	-	-	-	-	-
2-28-80	33	33	33	33	33	33	33	33	33	-	-	-	-	-	-
3-4-80	-	-	-	-	-	-	-	-	-	-	-	-	32	32	32
3-15-80	32	32	32	32	32	32	32	32	32	32	32	32	-	-	-

Table 18. Turbidity Data (NTU) at Surface (S), Middle (M), and Bottom (B) and Secchi Disc Disc Data in ft (m) for Air Bubbler Study, St. Marys River and Whitefish Bay, Michigan

	Stations														
Turbidity Date	1			2			3			4			5		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
10-2-79	-	-	-	0.7	-	1.2	0.4	-	0.6	0.6	-	0.7	-	-	-
10-5, 6-79	0.9	-	1.0	1.0	-	1.0	0.6	-	1.0	0.5	-	0.6	0.2	-	0.4
12-15-79	0.7	0.9	0.8	0.9	0.8	0.9	-	-	-	-	-	-	-	-	-
12-29-79	0.8	0.9	1.0	0.9	0.9	0.8	0.6	0.9	0.8	0.6	1.0	1.2	-	-	-
1-31-80	0.2	0.4	1.3	0.3	0.3	1.1	-	-	-	-	-	-	-	-	-
2-2, 5-80	-	-	-	-	-	-	0.3	0.3	0.5	0.2	0.3	0.7	-	-	-
2-15-80	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	3.2	-	-	-	-	-	-
2-28-80	0.2	0.2	0.3	-	0.3	0.6	0.2	0.3	4.6	-	-	-	-	-	-
3-4-80	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.3	0.3
3-15-80	0.3	0.2	0.3	0.3	0.3	0.4	0.5	0.8	0.9	0.2	0.2	0.2	-	-	-

Secchi Disc Date	1	2	3	4	5
10-2-79	-	7(2.1)	8(2.4)	-	-
10-5-79	8(2.4)	8(2.4)	12(3.7)	12(3.7)	35(10.7)*
12-29, 31-79	13(4.0)	13(4.0)	17(5.2)	19(5.8)	-
1-31-80	24(7.3)*	20(6.1)*	-	-	-
2-2, 5-80	-	-	27(8.2)	24(7.3)*	-
2-15-80	34(10.4)*	20(6.1)*	35(10.7)*	-	-
2-28-80	34(10.4)*	20(6.1)*	35(10.7)*	-	-
3-4-80	-	-	-	-	18(5.5)*
3-15-80	31(9.5)*	24(7.3)*	36(11.0)*	26(7.9)*	-

*Measurements to bottom of water column.

Table 19. Dissolved Oxygen Data (mg/l) at Surface (S), Middle (M), and Bottom (B) for Air Bubbler Study, St. Marys River and Whitefish Bay, Michigan

Date	Stations 1			2			3			4			5		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
10-2-79	-	-	-	10.5	-	10.5	10.5	-	10.1	10.5	-	10.1	10.2	-	10.2
10-5-79	10.3	-	10.2	10.2	-	10.2	10.5	-	10.1	10.3	-	10.2	10.0	-	10.1
12-15-79	14.0	13.9	13.9	14.1	13.9	14.1	-	-	-	-	-	-	-	-	-
12-29,31-79	13.6	13.6	13.7	13.8	13.7	13.7	13.6	13.7	13.6	13.6	13.6	13.6	-	-	-
1-31-80	14.2	14.5	14.3	14.2	14.1	14.1	-	-	-	-	-	-	-	-	-
2-2,5-80	13.9	14.1	14.0	12.8	12.2	12.4	-	-	-	-	-	-	-	-	-
2-15-80	15.8	15.2	15.5	15.3	-	14.6	15.3	15.5	15.8	-	-	-	-	-	-
2-28-80	14.3	14.1	14.2	14.2	14.3	14.2	14.1	14.2	14.1	-	-	-	-	-	-
3-4-80	-	-	-	-	-	-	-	-	-	-	-	-	13.7	14.0	13.9
3-15-80	14.4	14.3	14.1	14.5	14.4	14.1	14.3	-	14.2	14.1	14.1	14.0	-	-	-

Table 20. Velocity Data (fps) at Surface (S), Middle (M) and Bottom (B) for Air Bubbler Study, St. Marys River and Whitefish Bay, Michigan (fps x 0.305 = m/sec.).

Date	Stations 1			2			3			4			5		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
10-2-79	-	-	-	0.5	0.4	0.5	1.3	1.0	0.6	1.1	1.0	0.9		-	-
1-31-80	1.1	1.1	1.1	0.9	0.8	0.8	-	-	-	-	-	-		-	-
2-2, 5-80	-	-	-	-	-	-	0.9	0.8	1.0	0.5	0.4	0.4	-	-	-
2-15-80	1.2	1.4	1.1	0.9	1.1	1.0	1.0	1.0	1.0	-	-	-	-	-	-
2-28-80	1.1	1.2	1.3	1.1	1.2	1.2	0.9	1.1	1.1	-	-	-	-	-	-
3-4-80	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2
3-15-80	1.1	1.0	1.1	0.6	0.7	0.7	0.6	0.7	0.7	0.6	0.7	1.1	-	-	-

APPENDIX A

STANDARD LENGTH (SL) AND TOTAL LENGTH (TL) OF FISH CAPTURED IN BUBBLER STUDY, ST. MARYS RIVER AND WHITEFISH BAY, OCTOBER 1979-MARCH 1980. METRIC UNITS FOR MESH SIZE ARE 1"(25mm), 2"(51mm), 3"(76mm), 4.5"(114mm) and 5"(127mm).

APPENDIX A. Standard Length (SL), and Total Length (TL) of Fish Captured in Bubbler Study, St. Marys River and Whitefish Bay, October 1979-March 1980. Metric Units for Mesh Size are 1"(25 mm), 2"(51 mm), 3"(76 mm), 4.5"(114 mm) and 5"(127 mm). Exp. indicates experimental gill net.

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
1	10-3	Gill net	Exp.	Rock bass	1	142	180
2	10-3	Gill net	Exp.	Walleye	3	185-198	223-230
3	10-3	Gill net	Exp.	Northern pike	1	430	553
4	10-3	Gill net	Exp.	White sucker	1	195	233
1	10-5	Hoop net		Smallmouth bass	7	91-226	108-234
				Rock bass	5	120-174	150-213
		Fyke net		Smallmouth bass	2	175-234	206-280
				Rock bass	3	115-160	128-194
2	10-5	Hoop net		Rock bass	9	61-196	74-241
		Fyke net		Rock bass	33	56-199	70-239
1	1-1	Gill net	3	Northern pike	1	580	670
				Cisco	1	330	400
	1-1	Gill net	3	Northern pike	2	383-485	455-565
	12-30	Hoop net		Burbot	1	140	158
	1-26	Set line		Burbot	2	485-490	560-575
	1-27	Set line		Burbot	2	490-660	555-770
	1-28	Set line		Burbot	4	390-610	445-700
	1-29	Set line		Burbot	2	580-590	665-670
	1-26	Gill net	3	Northern pike	1	440	525
	1-26	Gill net	3	Burbot	1	480	520
	1-27	Gill net	5	Burbot	1	495	565
	2-12	Gill net	3	Longnose sucker	1	266	310
	2-20	Gill net	3	Burbot	1	457	559
	2-14	Gill net	4.5	Burbot	1	454	530

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
	2-16	Gill net	2	Burbot	1	235	271
	2-13	Set line		Burbot	2	380-505	440-565
	2-14	Set line		Burbot	3	400-460	460-550
	2-15	Set line		Burbot	3	480-670	565-770
	2-16	Set line		Burbot	4	420-478	475-555
	2-28	Gill net	4.5	Northern pike	1	490	582
	2-26	Set line		Burbot	6	375-[illegible]	435-800
	2-27	Set line		Burbot	6	440-[illegible]	510-735
	2-28	Set line		Burbot	1	71[illegible]	800
	3-17	Gill net	1	Rainbow smelt	1	135	155
	3-17	Gill net	3	Longnose sucker	1	304	313
	3-17	Gill net	Exp.	Longnose sucker	2	340-360	430-495
	3-20	Set line		Burbot	3	385-630	440-735
	3-21	Set line		Burbot	2	459-625	530-720
	3-19	Gill net	1	Rainbow smelt	1	122	150
	3-20	Gill net	1	Rainbow smelt	2	110-121	132-146
	3-21	Gill net	4.5	Walleye	1	415	507
	3-19	Gill net	4.5	Burbot	1	575	661
	3-21	Gill net	4.5	Walleye	1	390	470
	3-19	Gill net	4.5	Burbot	1	560	663
2	12-28	Gill net	3	Cisco	1	308	375
	1-1	Gill net	Exp.	Northern pike	1	545	629
	1-25	Set line		Burbot	3	455-555	483-590
	1-26	Set line		Burbot	5	355-600	410-690
	1-27	Set line		Burbot	2	465-475	540-555
	1-28	Set line		Burbot	1	540	630
	1-29	Set line		Burbot	1	510	580
	1-26	Gill net	3	Northern pike	1	405	473
	1-31	Gill net	3	Northern pike[a]	1	405	473

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
	1-28	Gill net	4.5	Burbot	1	475	545
	1-25	Gill net	5	Burbot	2	590-595	620-635
	1-26	Gill net	5	Burbot	1	470	550
	1-27	Gill net	5	Burbot	2	550-595	620-685
	1-28	Gill net	5	Burbot	1	505	590
	2-13	Set line		Burbot	1	450	515
	2-14	Set line		Burbot	1	485	565
	2-15	Set line		Burbot	1	580	675
	2-16	Gill net	5	Burbot	1	475	563
	2-20	Gill net	2	Cisco	2	195-205	240-245
	2-26	Gill net	Exp.	Burbot	1	450	520
				Rainbow smelt	1	130	155
	2-26	Set line		Burbot[a]	3	480-530	560-614
	2-27	Set line		Burbot	5	415-555	490-645
	2-28	Set line		Burbot	3	435-630	513-735
	2-29	Gill net	4.5	White sucker	1	375	467
	2-29	Gill net	4.5	Burbot	1	500	591
	3-17	Gill net	3	Cisco	1	250	305
				Northern pike	1	435	500
	3-14	Gill net	1	Rainbow smelt	1	142	165
	3-17	Gill net	1	Rainbow smelt	1	130	151
	3-20	Set line		Burbot	1	505	580
	3-21	Set line		Burbot	2	390-605	460-708
	3-21	Gill net	4.5	Whitefish	1	440	537
				Cisco	1	350	426
3	12-29	Gill net	3	Cisco	1	330	402
	1-2	Gill net	4.5	Whitefish	1	430	510
				Cisco	1	350	420
				Burbot	1	630	740
				White sucker	1	380	460

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	TL
-	1-1	Gill net	Exp.	Northern pike	1	710	800
				Yellow perch	1	250	295
				White sucker	4	350-395	420-480
	1-2	Gill net	Exp.	Northern pike	3	465-510	540-600
				White sucker	3	350-390	420-475
				Yellow perch	1	178	210
	1-27	Set line		Burbot	6	470-635	555-720
	1-28	Set line		Burbot	5	410-570	465-650
	1-29	Set line		Burbot	4	400-515	460-590
	1-30	Set line		Burbot	1	435	495
	1-29	Gill net	2	Cisco	1	305	375
				Yellow perch	1	190	235
	1-30	Gill net	2	Cisco	4	300	362-420
	1-31	Gill net	2	Cisco	1	300	370
	2-2	Gill net	2	Yellow perch	1	230	271
	1-28	Gill net	3	Whitefish	1	300	370
	1-29	Gill net	3	Burbot	2	265-390	325-480
	1-28	Gill net	4.5	Cisco	1	335	415
				Burbot	2	480-520	560-610
	1-29	Gill net	4.5	White sucker	1	390	480
	1-31	Gill net	4.5	White sucker	1	380	490
	1-30	Gill net	Exp.	Rainbow smelt	2	122-123	141-145
	2-13	Set line		Burbot	2	445-490	510-570
	2-14	Set line		Burbot	2	420-510	490-595
	2-15	Set line		Burbot	4	380-458	450-530
	2-16	Set line		Burbot	2	390-440	450-490
	2-14	Gill net	4.5	Burbot	2	460-535	530-615
	2-15	Gill net	4.5	Burbot	1	555	615
	2-16	Gill net	4.5	Northern pike	1	495	605

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
	2-16	Gill net	Exp.	White sucker	1	370	450
	2-21	Gill net	4.5	White sucker	3	385-395	465-481
				Cisco	2	315-335	386-411
	2-22	Gill net	4.5	Cisco	2	345-355	422-443
				White sucker	1	355	443
				Northern pike	1	550	643
	2-19	Gill net	4.5	Northern pike	1	610	710
				White sucker	1	380	465
	2-21	Gill net	4.5	Yellow perch	1	270	325
				Burbot	1	475	554
	2-22	Gill net	4.5	Cisco	2	365-370	438-451
				Northern pike	1	530	619
				Walleye	1	430	524
	2-22	Gill net	3	Northern pike	1	440	520
				White sucker[a]	1	385	472
	2-26	Gill net	4.5	Cisco	3	350-360	424-435
				White sucker	1	395	487
	2-27	Gill net	4.5	Yellow perch	1	290	344
				Cisco	2	360	430
				White sucker	3	350-435	430-514
	2-26	Gill net	4.5	Whitefish	1	380	459
	2-27	Gill net	4.5	Cisco	2	355-360	427-435
	2-26	Gill net	4.5	Northern pike	1	550	645
				Whitefish	1	350	426
	2-27	Gill net	4.5	Whitefish	1	380	464
				Cisco	1	360	438
	2-26	Gill net	4.5	Cisco	3	355-375	425-440
	2-27	Gill net	4.5	White sucker	1	381	465
	2-26	Gill net	3	Cisco	4	305-360	365-434
				White sucker	1	295	355

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	TL
	2-27	Gill net	3	Cisco	1	340	416
	2-26	Set line		Burbot	7	445-640	522-710
	2-27	Set line		Burbot	2	525-580	610-680
	3-5	Set line		Burbot	1	585	670
	3-5	Gill net	1	Rainbow smelt	1	123	147
	3-15	Gill net	3	Cisco	1	297	376
				Northern pike	2	368-565	425-656
	3-15	Gill net	4.5	Cisco	1	355	437
				Northern pike	2	520-652	610-746
	3-15	Gill net	1	Rainbow smelt	3	120-137	145-162
	3-17	Gill net	3	White sucker	1	365	430
	3-17	Gill net	4.5	White sucker	1	380	445
	3-17	Gill net	4.5	Burbot	1	569	685
				White sucker	1	393	463
	3-17	Gill net	4.5	Whitefish	1	410	470
	3-19	Gill net	1	Rainbow smelt	9	115-136	136-160
				Yellow perch	1	81	100
				Trout-perch	1	8[illegible]	110
	3-21	Gill net	1	Rainbow smelt	4	120-1[illegible]	148-160
	3-19	Gill net	3	Cisco	1	340	405
	3-21	Gill net	3	Cisco[a]	2	295-340	366-405
	3-19	Gill net	4.5	Rainbow trout	1	415	477
				Northern pike	1	552	659
	3-21	Gill net	4.5	Northern pike[a]	1	552	659
	3-18	Gill net	3	Cisco	4	315-357	370-416
				Rock bass	1	158	191
	3-19	Gill net	3	Northern pike	2	555-575	655-676
				Cisco[a]	5	305-350	370-410

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
	3-21	Gill net	3	Yellow perch	2	198-230	236-255
				White sucker	1	330	410
				Cisco	11	290-360	360-446
	3-18	Set line		Burbot	4	540-700	580-800
	3-19	Set line		Burbot	5	420-515	481-580
4	1-1	Gill net	3	Northern pike	2	465-482	537-560
	1-2	Gill net	3	Northern pike	1	470	560
	1-1	Gill net	2	Brook trout	1	218	254
	1-2	Gill net	2	Northern pike	1	265	310
				Cisco	1	193	235
	1-1	Gill net	5	Burbot	1	565	603
	2-5	Gill net	5	Burbot	3	540-635	635-730
	2-5	Gill net	4.5	Northern pike	2	580-630	660-720
				Splake	1	355	405
				Burbot	4	462-550	525-620
	2-6	Gill net	4.5	Whitefish	1	445	521
				Longnose sucker	1	425	495
				White sucker	1	432	508
				Burbot	1	508	565
	2-7	Gill net	4.5	Whitefish	2	465-490	547-572
				Longnose sucker	1	330	399
				White sucker	1	355	430
	2-8	Gill net	4.5	Burbot	1	520	600
	2-8	Gill net	3	Longnose sucker	1	285	346
	2-7	Gill net	Exp.	Longnose sucker	1	355	429
	2-6	Set line		Burbot	4	489-597	540-686
	2-7	Set line		Burbot	2	490-550	545-615
	2-8	Set line		Burbot	2	410-460	473-538
	2-20	Gill net	4.5	Longnose sucker	1	380	457

(Continued)

Appendix A (Continued)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	TL
5	2-21	Gill net	4.5	Longnose sucker	3	330-370	403-448
	2-22	Gill net	4.5	Longnose sucker	1	370	454
	2-20	Gill net	4.5	Rainbow trout	1	455	532
	2-21	Gill net	4.5	Longnose sucker	2	340-383	408-474
	3-20	Gill net	3	Burbot	1	385	442
	3-12	Gill net	4.5	Burbot	1	500	582
	3-15	Gill net	4.5	Burbot	1	525	615
	3-17	Gill net	4.5	Burbot	1	510	590
	3-17	Gill net	3	Burbot	1	390	450
	3-17	Set line		Burbot	3	420-740	490-860
	3-18	Set line		Burbot	2	445	510-520
	3-19	Set line		Burbot	2	422-545	480-610
	3-19	Gill net	4.5	Northern pike	1	480	568
	3-4	Set line		Burbot	2	490-555	580-653
	3-6	Set line		Burbot	4	315-555	367-640
	3-8	Set line		Burbot	1	512	597
	3-4	Gill net	1	Rainbow smelt	11	120-155	139-182
	3-6	Gill net	1	Rainbow smelt	7	122-151	144-178
	3-8	Gill net	1	Rainbow smelt	3	133-146	159-171
	3-6	Gill net	4.5	Northern pike	3	635-645	731-750
				White sucker	1	390	472
	3-8	Gill net	4.5	Burbot	1	609	699
				Northern pike	3	578-[illegible]09	673-724
	3-4	Gill net	4.5	Northern pike	3	575-[illegible]	685-750
				White sucker	1	36[illegible]	454
	3-6	Gill net	4.5	Northern pike	2	560-675	650-780
				White sucker	1	345	437
	3-8	Gill net	4.5	Northern pike	1	648	756

(Continued)

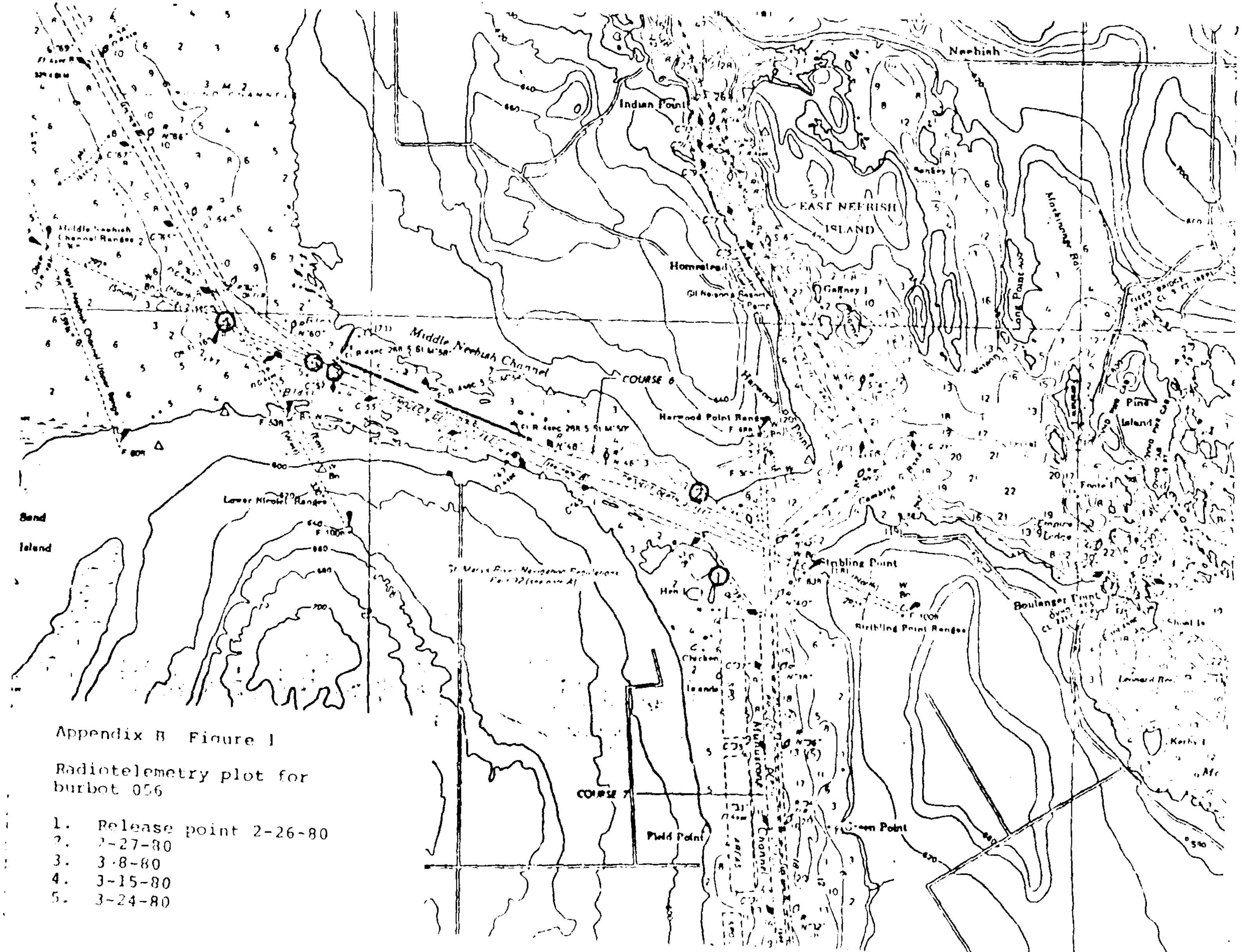
Appendix A (Concluded)

Station	Date	Gear	Mesh (Inches)	Species	Number Caught	Length Range (mm) SL	Length Range (mm) TL
	3-8	Gill net	3	Northern pike	1	597	705
				Cisco	1	368	432
	3-4	Gill net	3	Northern pike	2	645-655	760-770
	3-6	Gill net	3	Northern pike	1	460	544
	3-8	Gill net	3	Northern pike	1	451	533
	3-6	Gill net	Exp.	Rainbow smelt	1	131	154

[a] Recaptures of tagged or marked fish

APPENDIX B

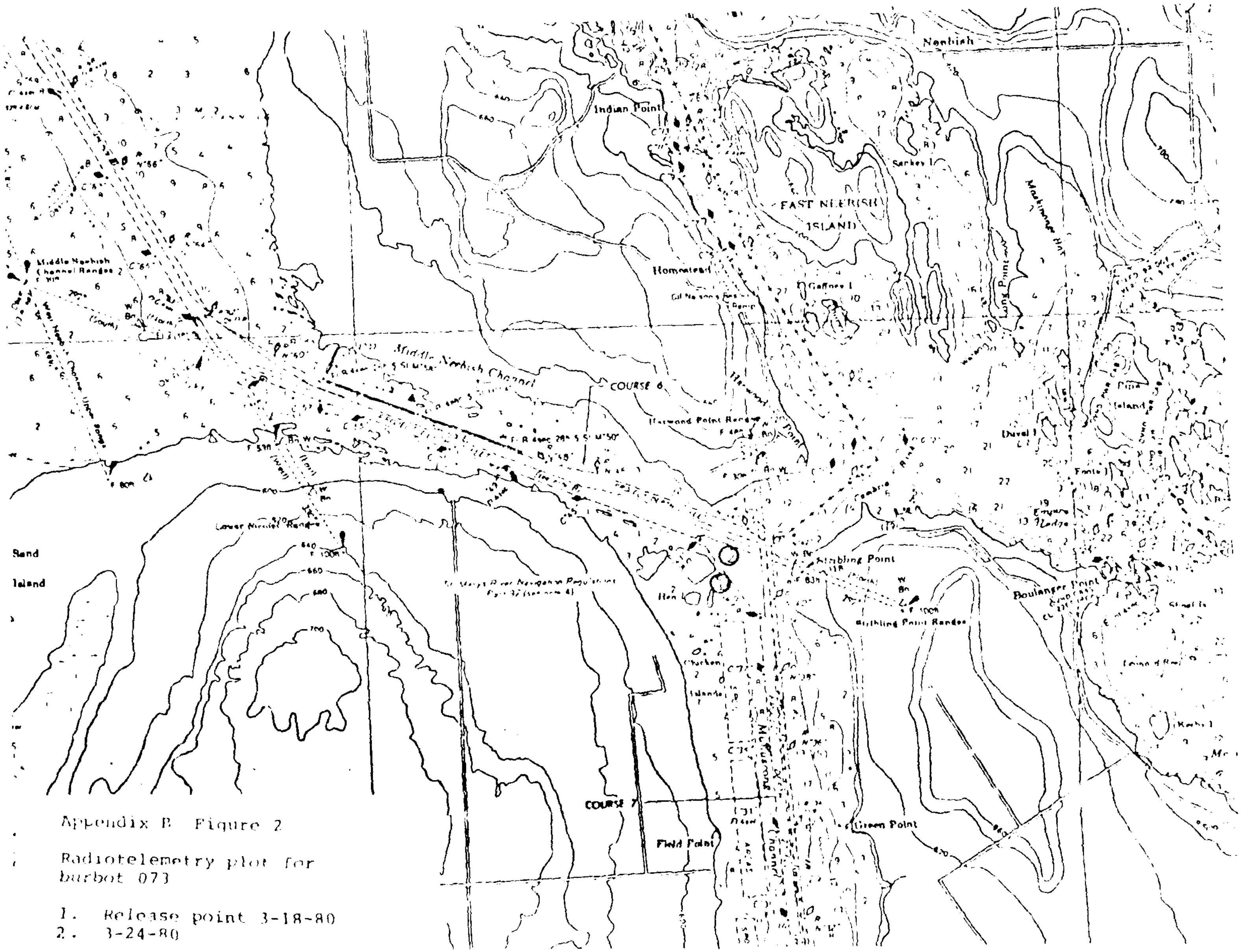
RADIOTELEMETRY PLOTS FOR FISH TRACKED IN ST. MARYS RIVER, FEBRUARY AND MARCH, 1980.



Appendix B Figure 1

Radiotelemetry plot for burbot 056

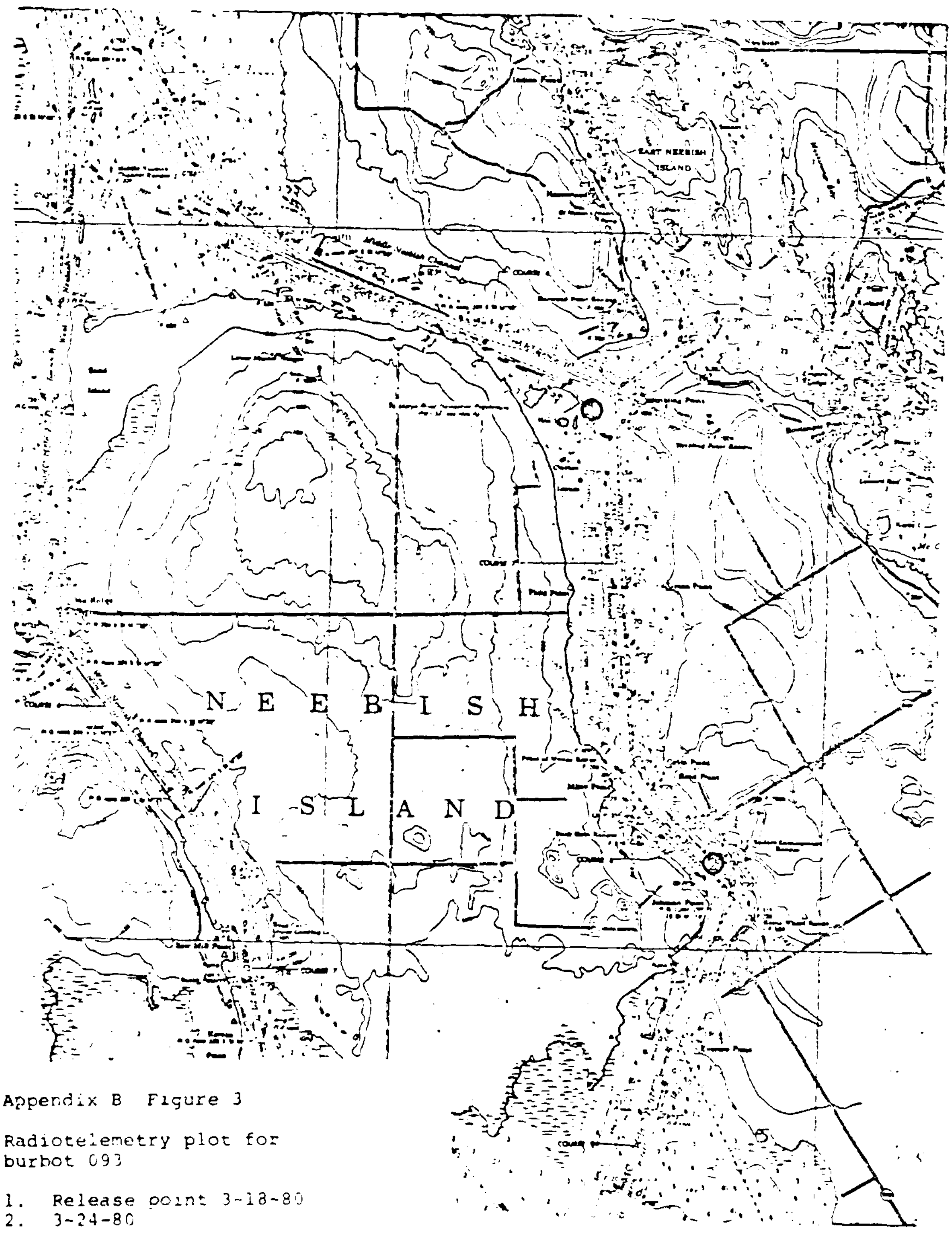
1. Release point 2-26-80
2. 2-27-80
3. 3-8-80
4. 3-15-80
5. 3-24-80



Appendix B Figure 2

Radiotelemetry plot for burbot 073

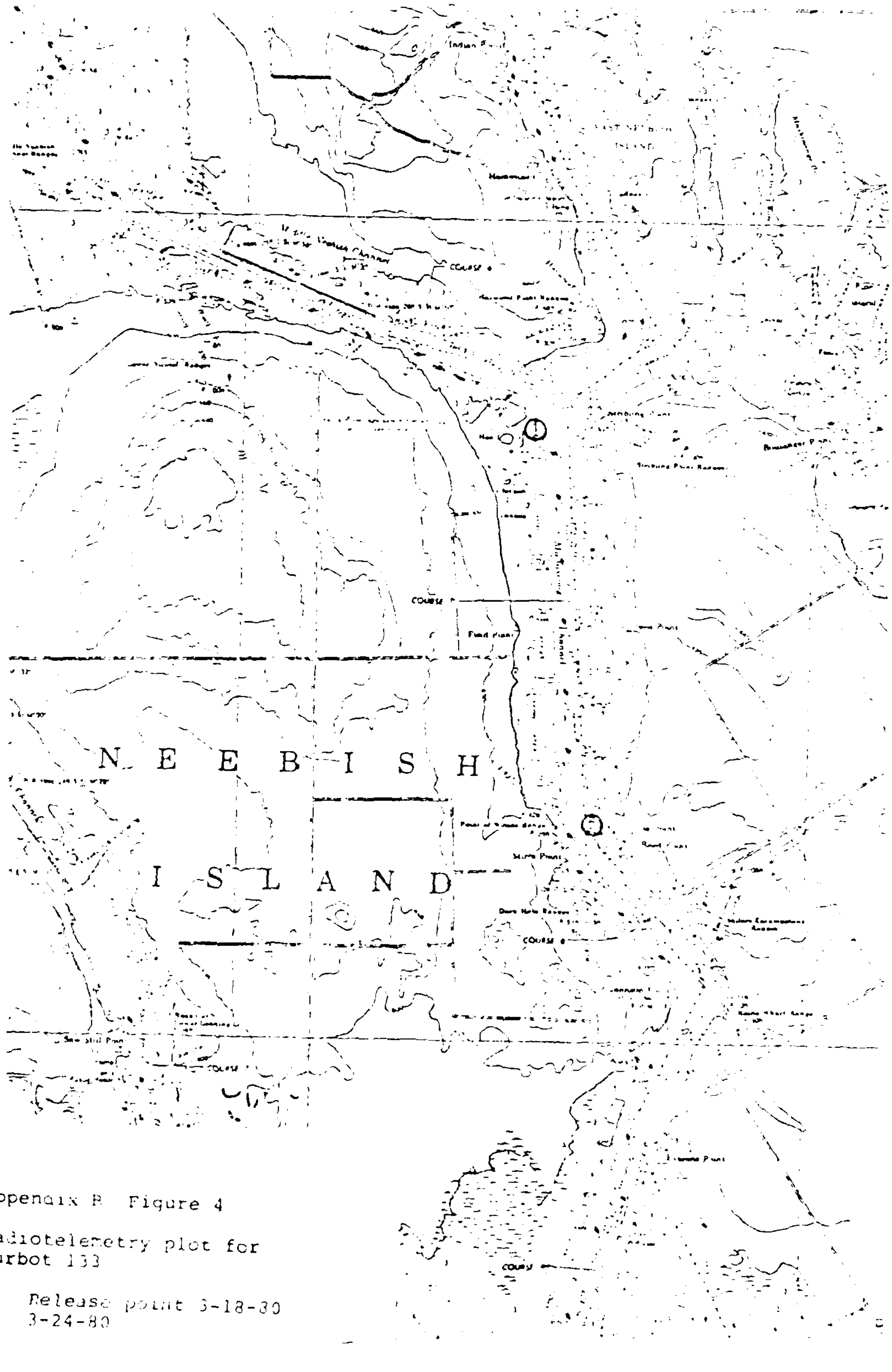
1. Release point 3-18-80
2. 3-24-80



Appendix B Figure 3

Radiotelemetry plot for burbot 093

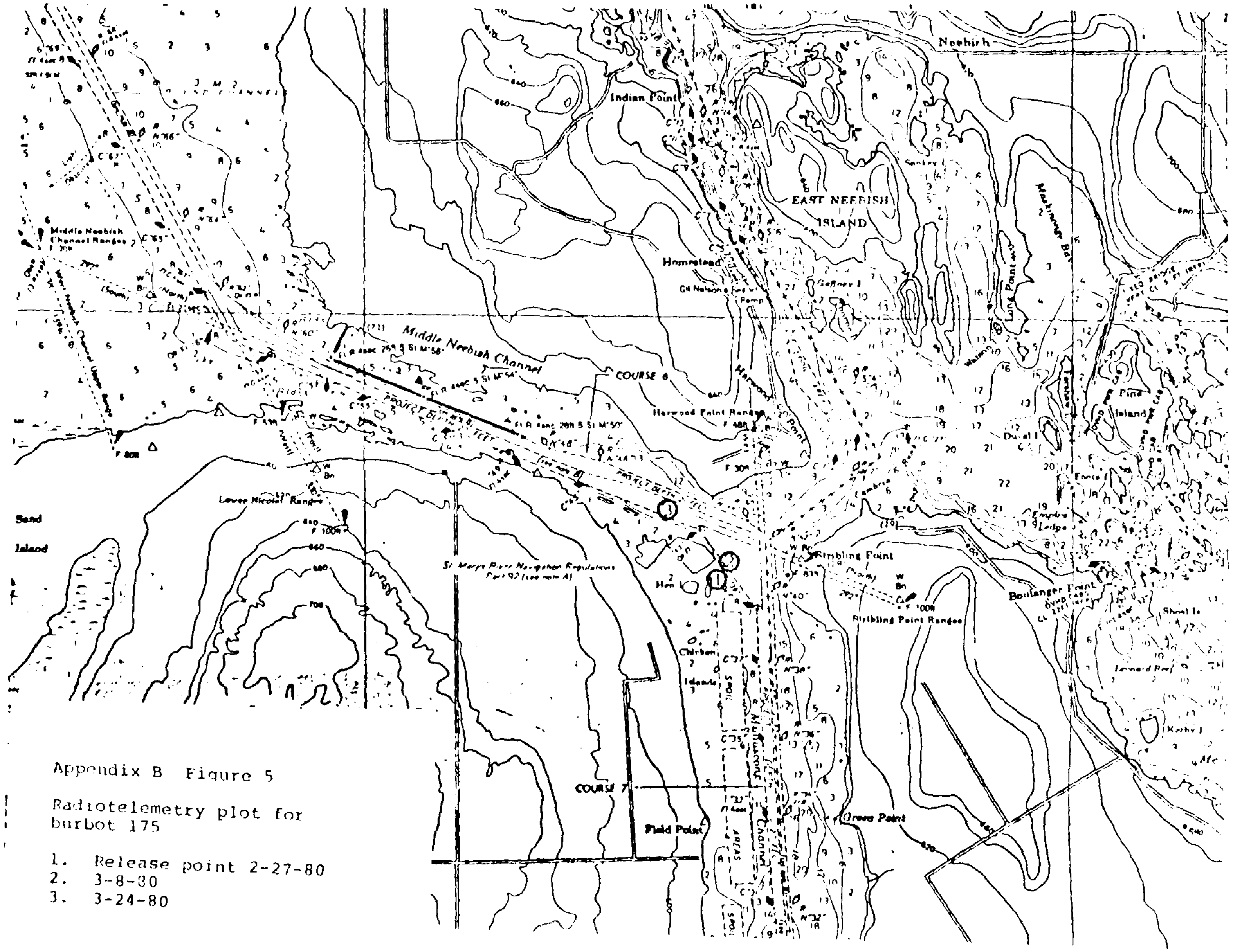
1. Release point 3-18-80
2. 3-24-80



Appendix B Figure 4

Radiotelemetry plot for burbot 133

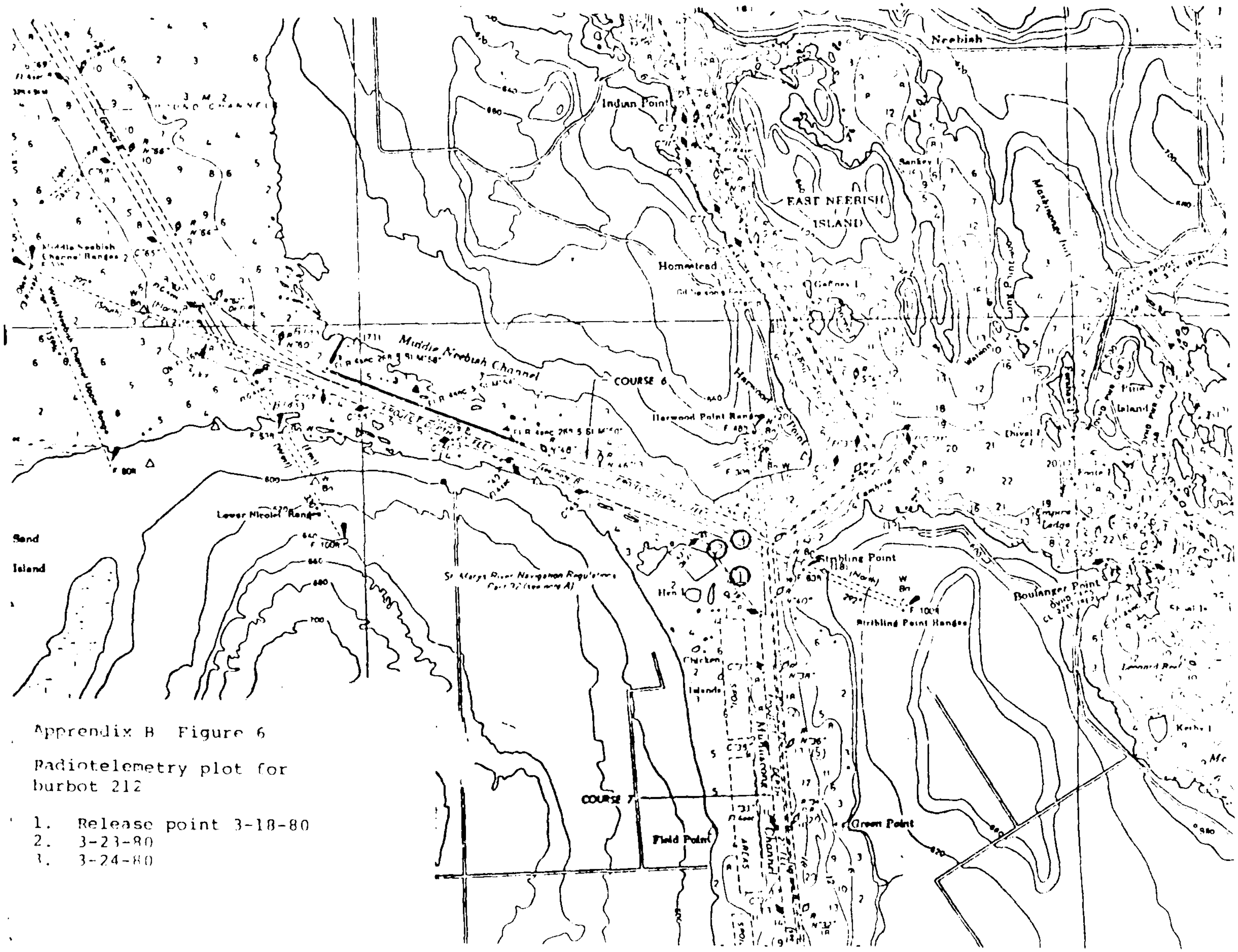
1. Release point 3-18-80
2. 3-24-80



Appendix B Figure 5

Radiotelemetry plot for burbot 175

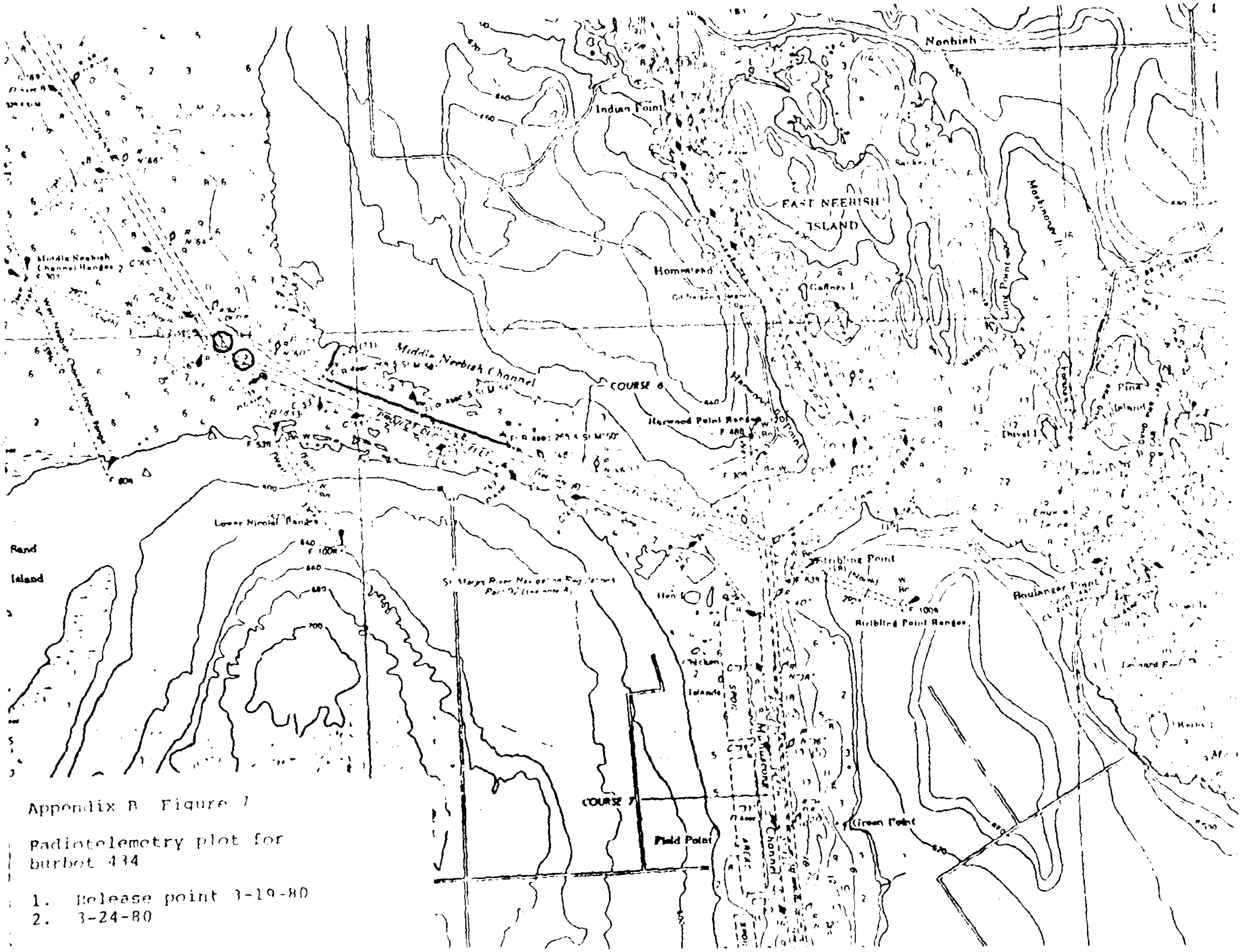
1. Release point 2-27-80
2. 3-8-30
3. 3-24-80



Apprendix B Figure 6

Radiotelemetry plot for burbot 212

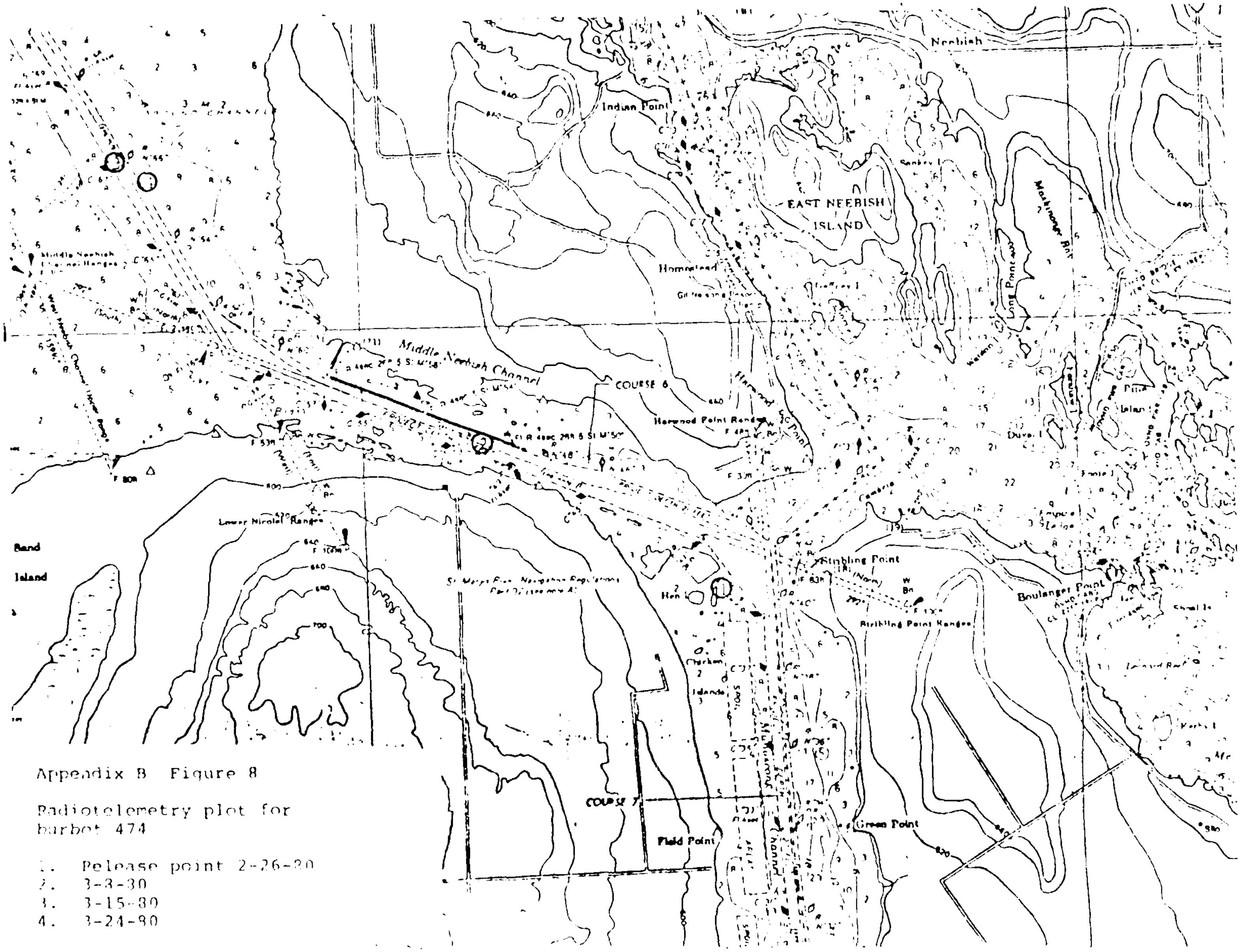
1. Release point 3-18-80
2. 3-23-80
3. 3-24-80



Appendix B Figure 7

Radiotelemetry plot for
burbot 434

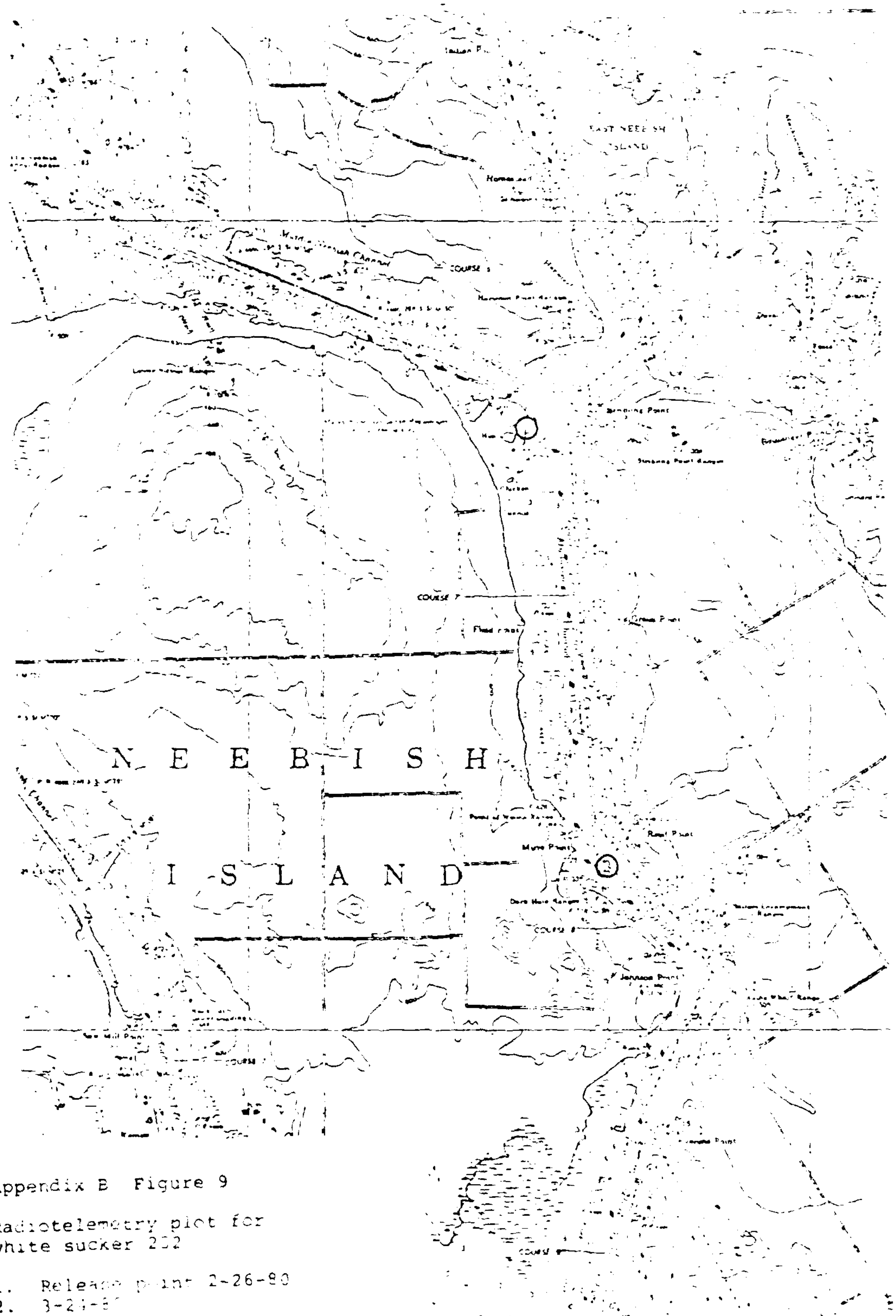
1. Release point 3-19-80
2. 3-24-80



Appendix B Figure 8

Radiotelemetry plot for burbot 474

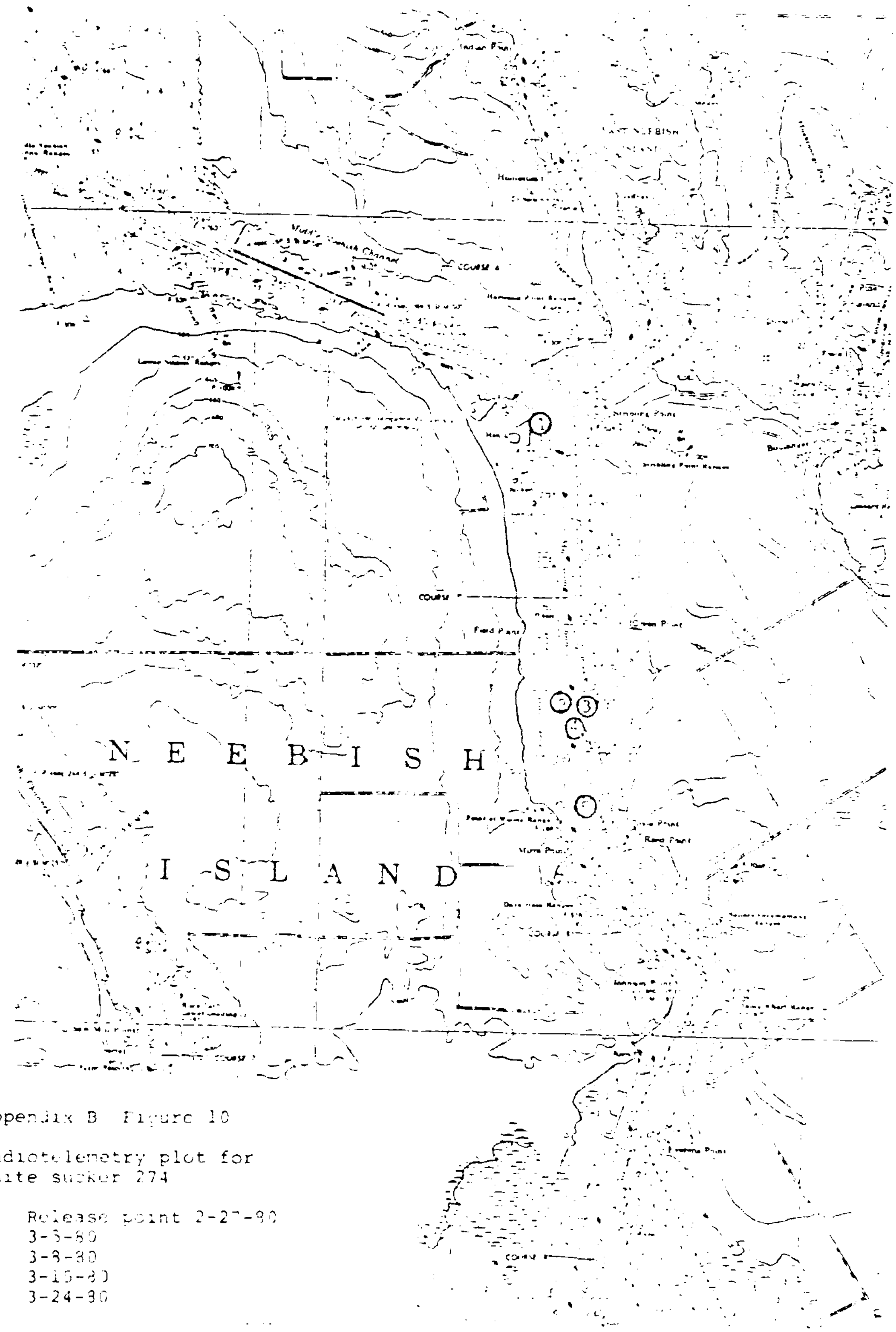
1. Release point 2-26-80
2. 3-3-80
3. 3-15-80
4. 3-24-80



Appendix B Figure 9

Radiotelemetry plot for
white sucker 2[illegible]2

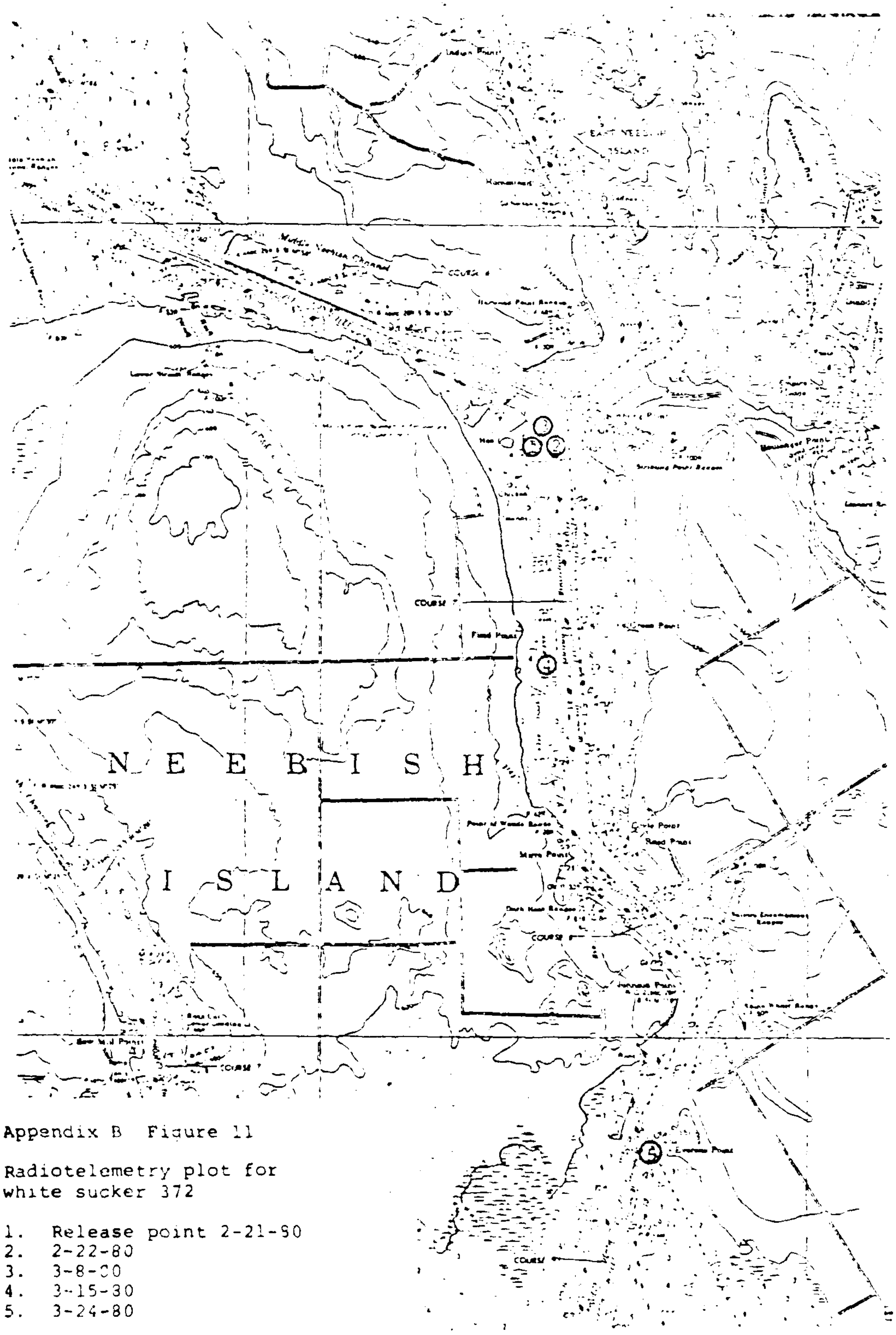
1. Release point 2-26-80
2. 3-2[illegible]-8[illegible]



Appendix B Figure 10

Radiotelemetry plot for
white sucker 274

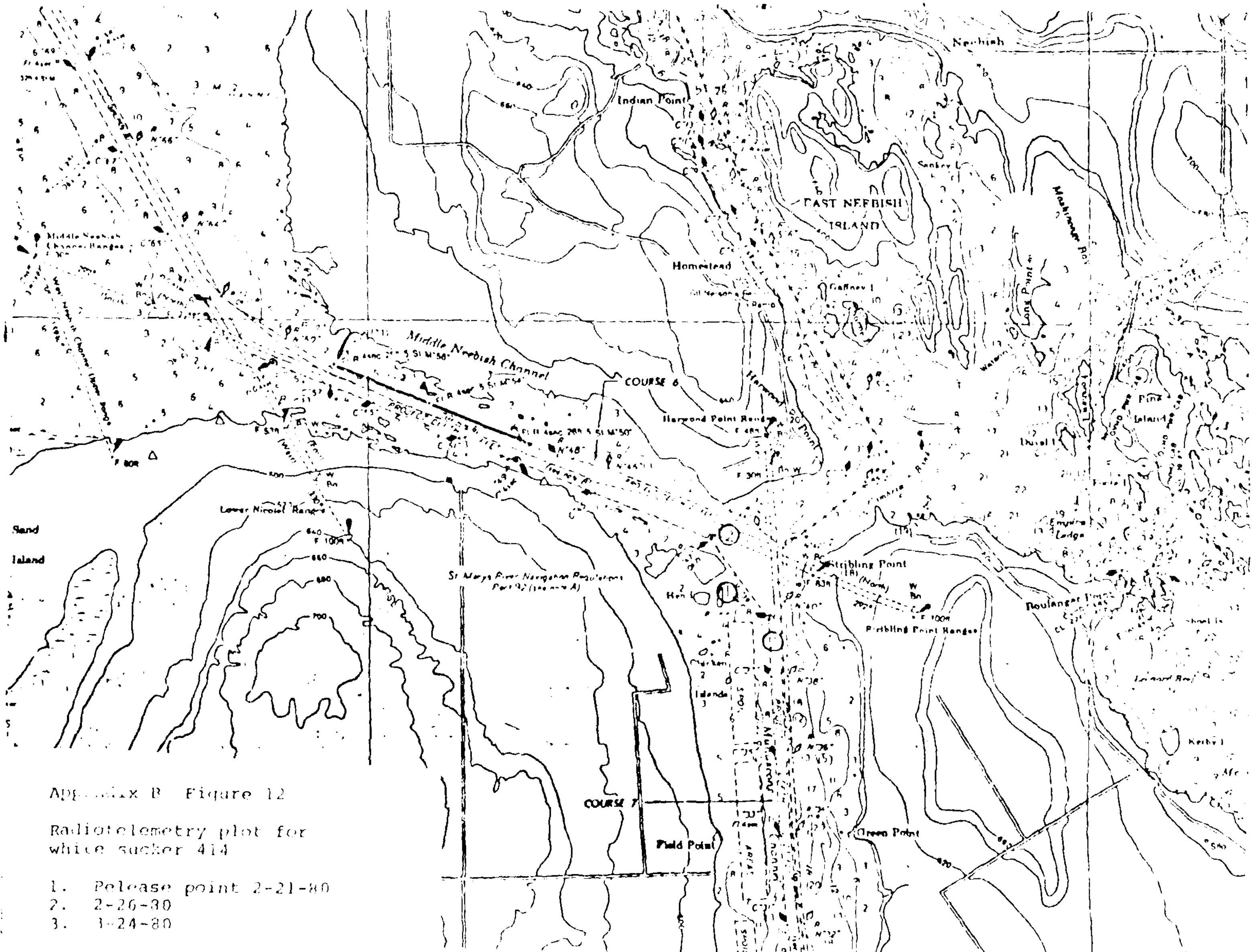
1. Release point 2-27-80
2. 3-5-80
3. 3-8-80
4. 3-15-80
5. 3-24-80



Appendix B Figure 11

Radiotelemetry plot for
white sucker 372

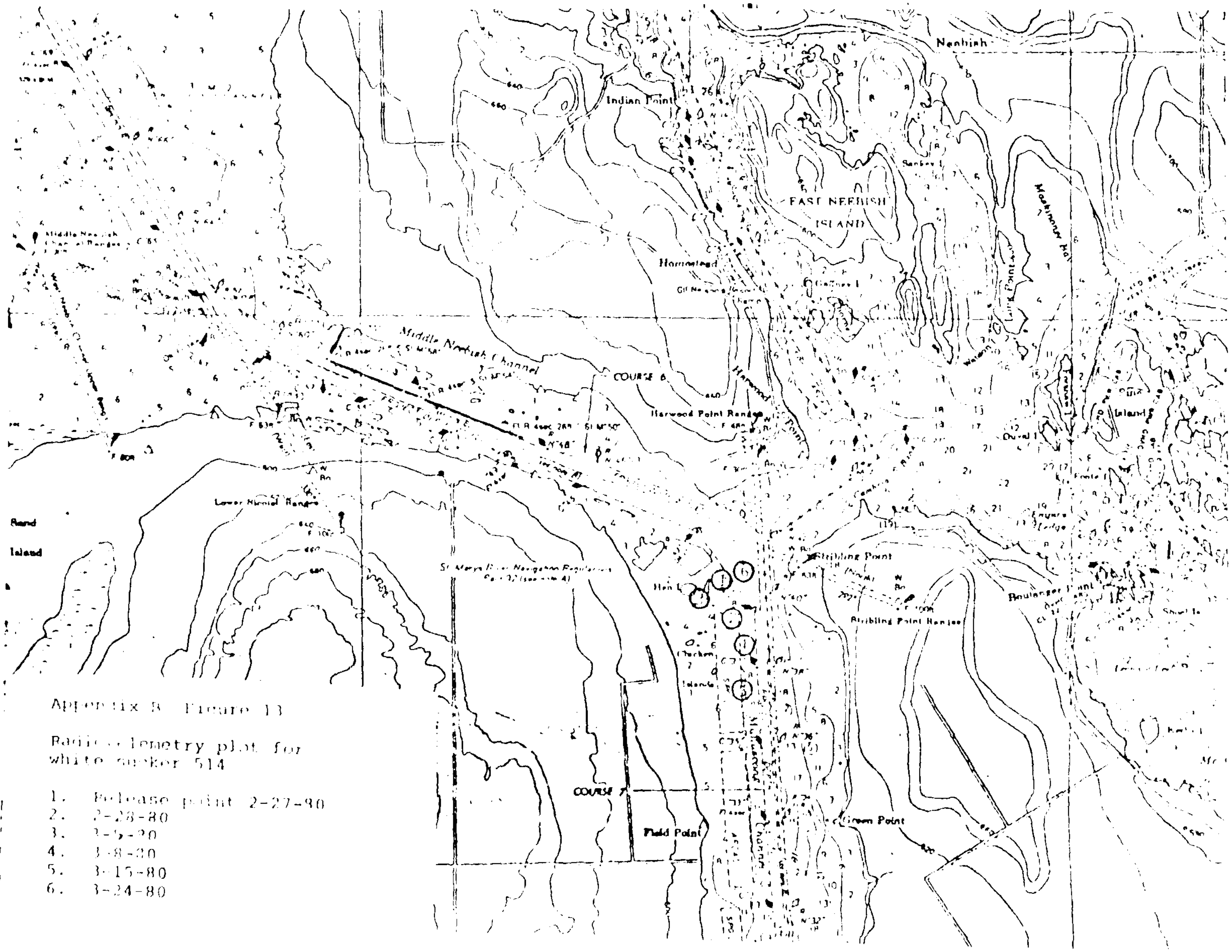
1. Release point 2-21-80
2. 2-22-80
3. 3-8-80
4. 3-15-80
5. 3-24-80



Appendix B Figure 12

Radiotelemetry plot for white sucker 414

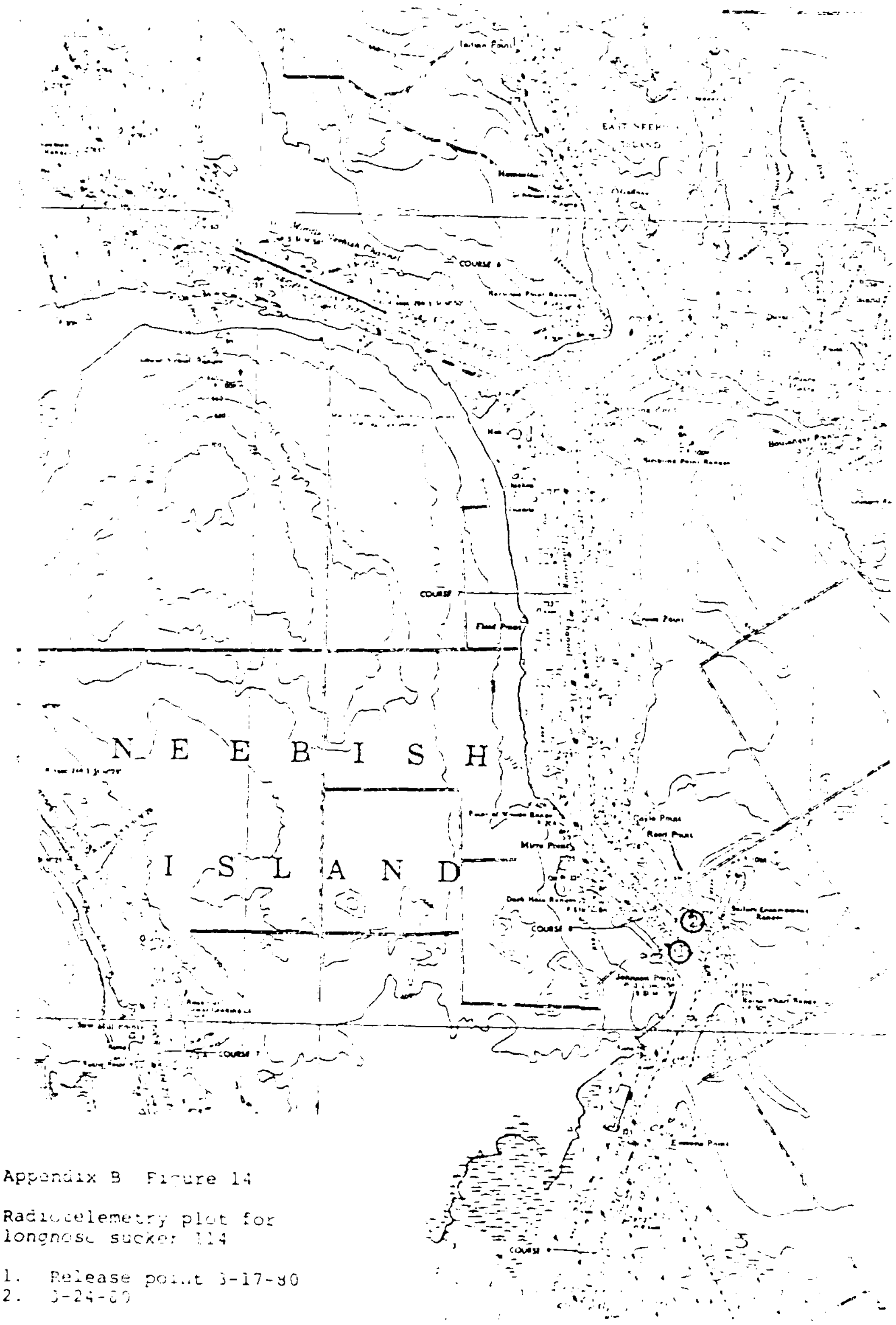
1. Release point 2-21-80
2. 2-26-80
3. 3-24-80



Appendix B Figure 13

Radio-telemetry plot for white sucker 514

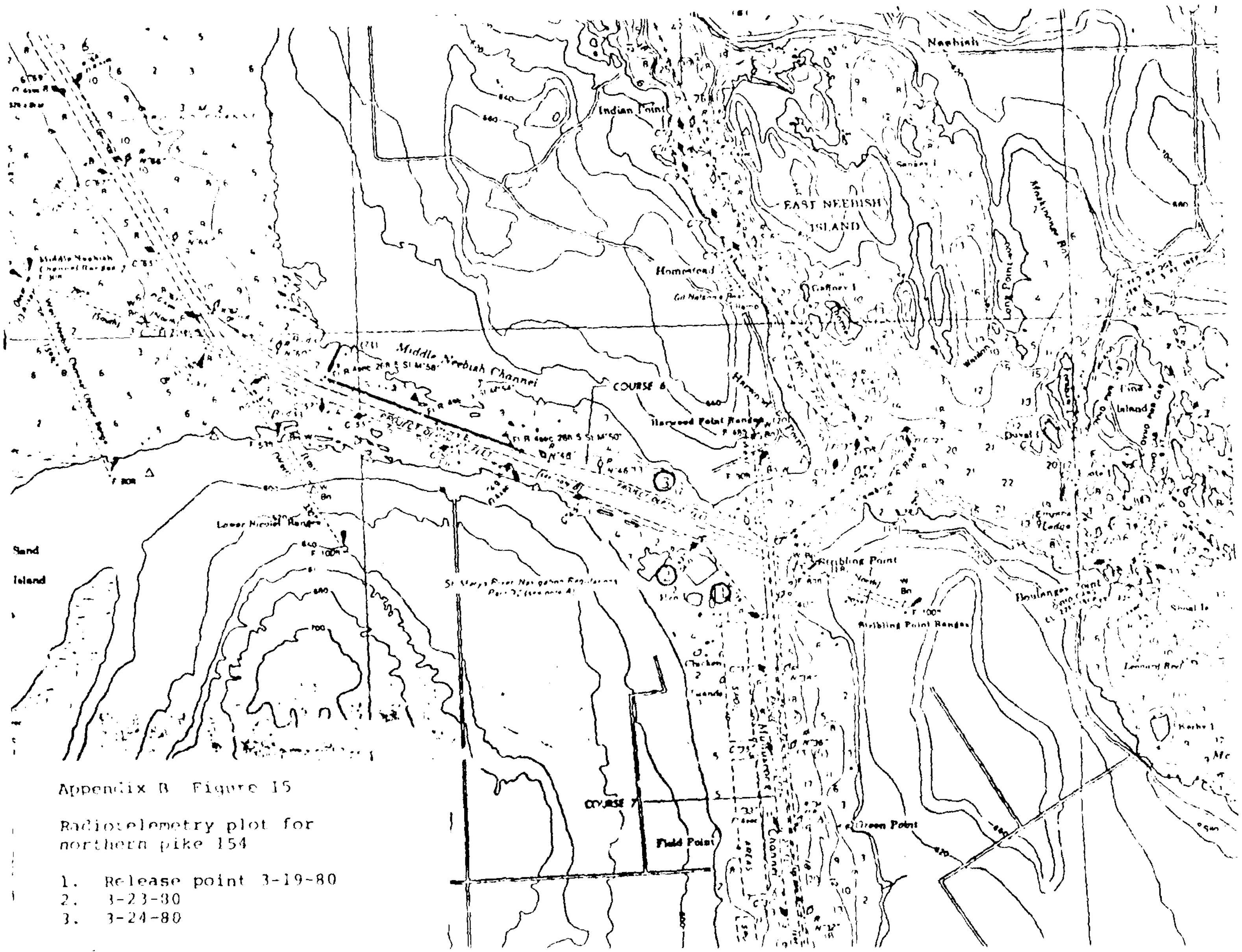
1. Release point 2-27-80
2. 2-28-80
3. 3-5-80
4. 3-8-80
5. 3-15-80
6. 3-24-80



Appendix B Figure 14

Radiotelemetry plot for longnose sucker 114

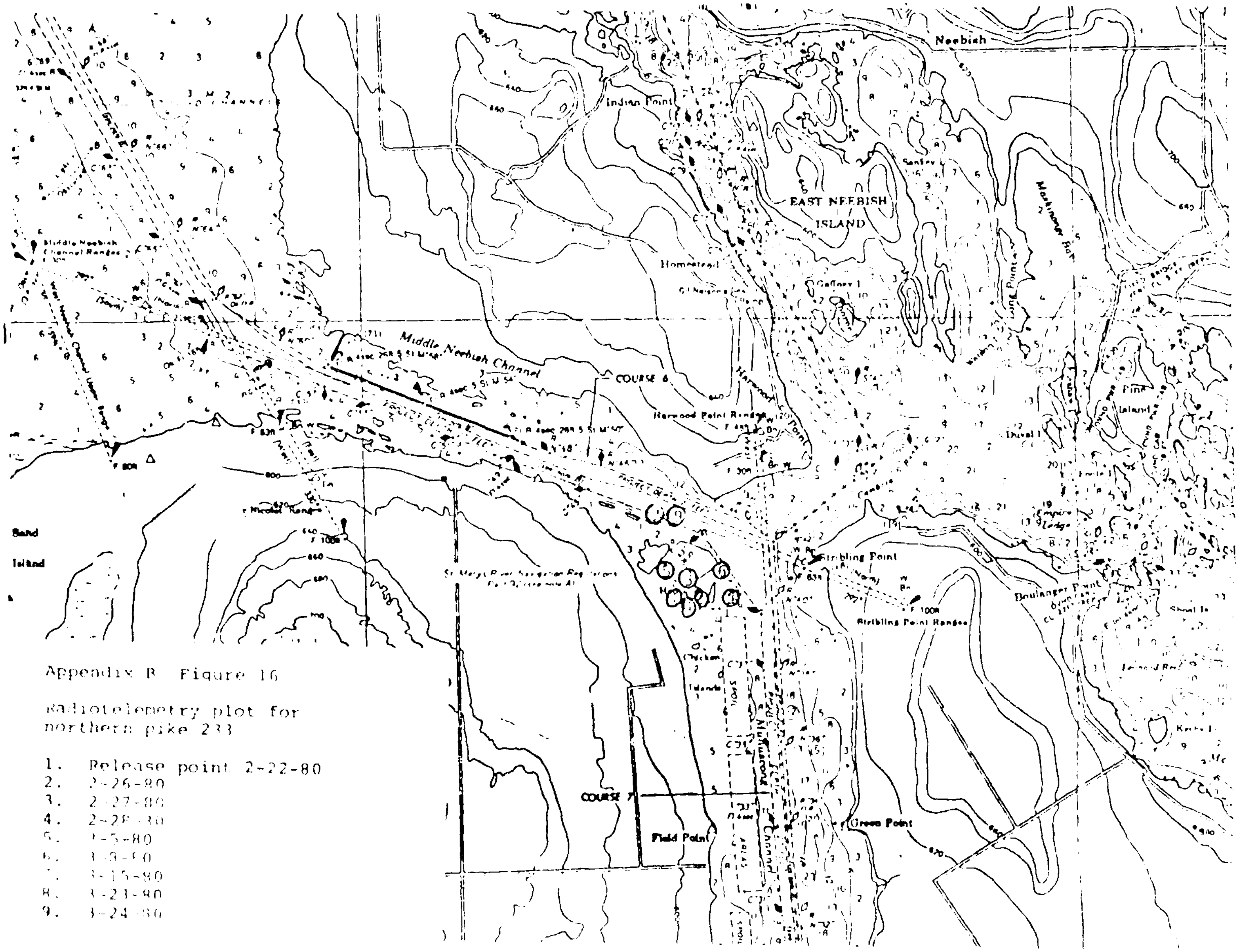
1. Release point 5-17-80
2. 5-24-80



Appendix B Figure 15

Radiotelemetry plot for
northern pike 154

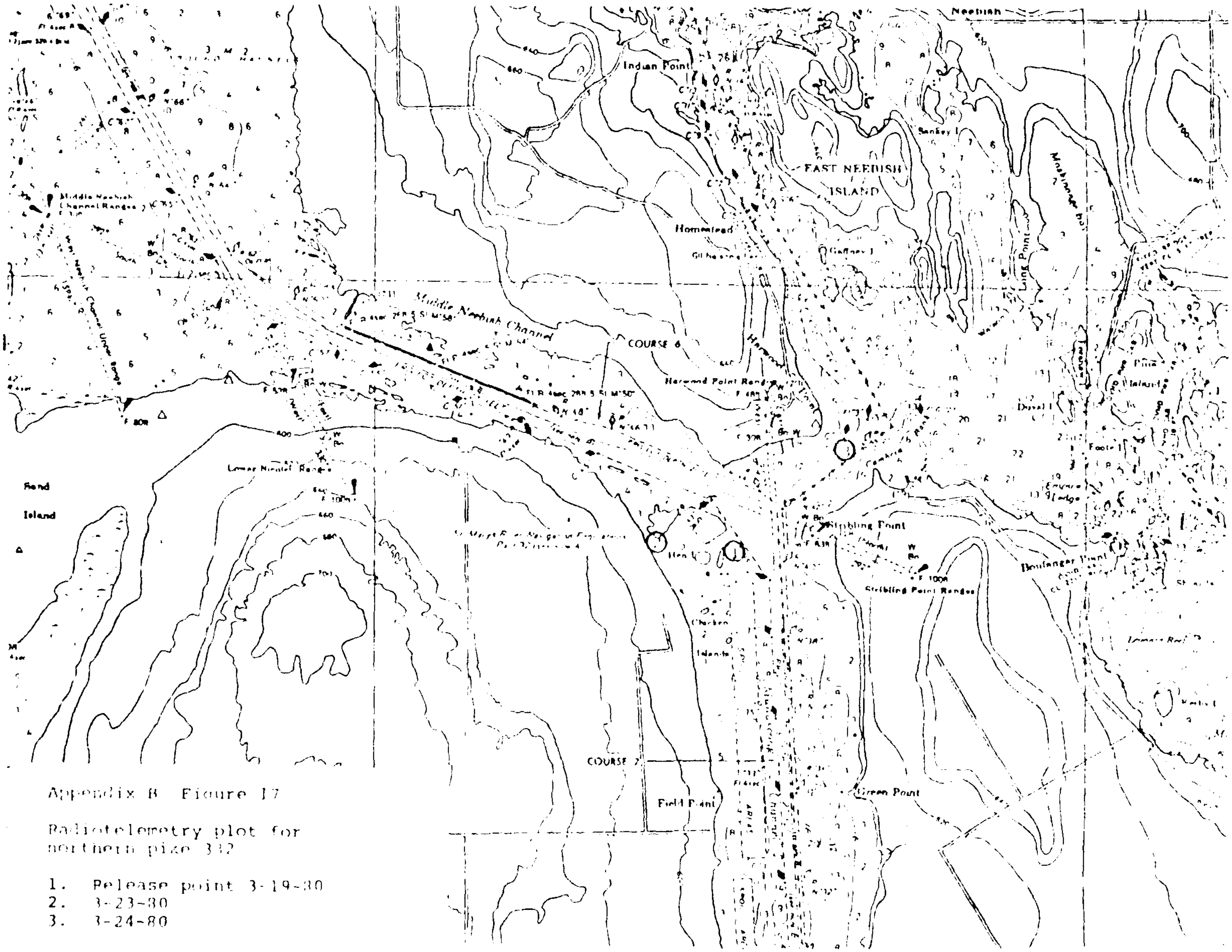
1. Release point 3-19-80
2. 3-23-80
3. 3-24-80



Appendix B Figure 16

Radiotelemetry plot for northern pike 233

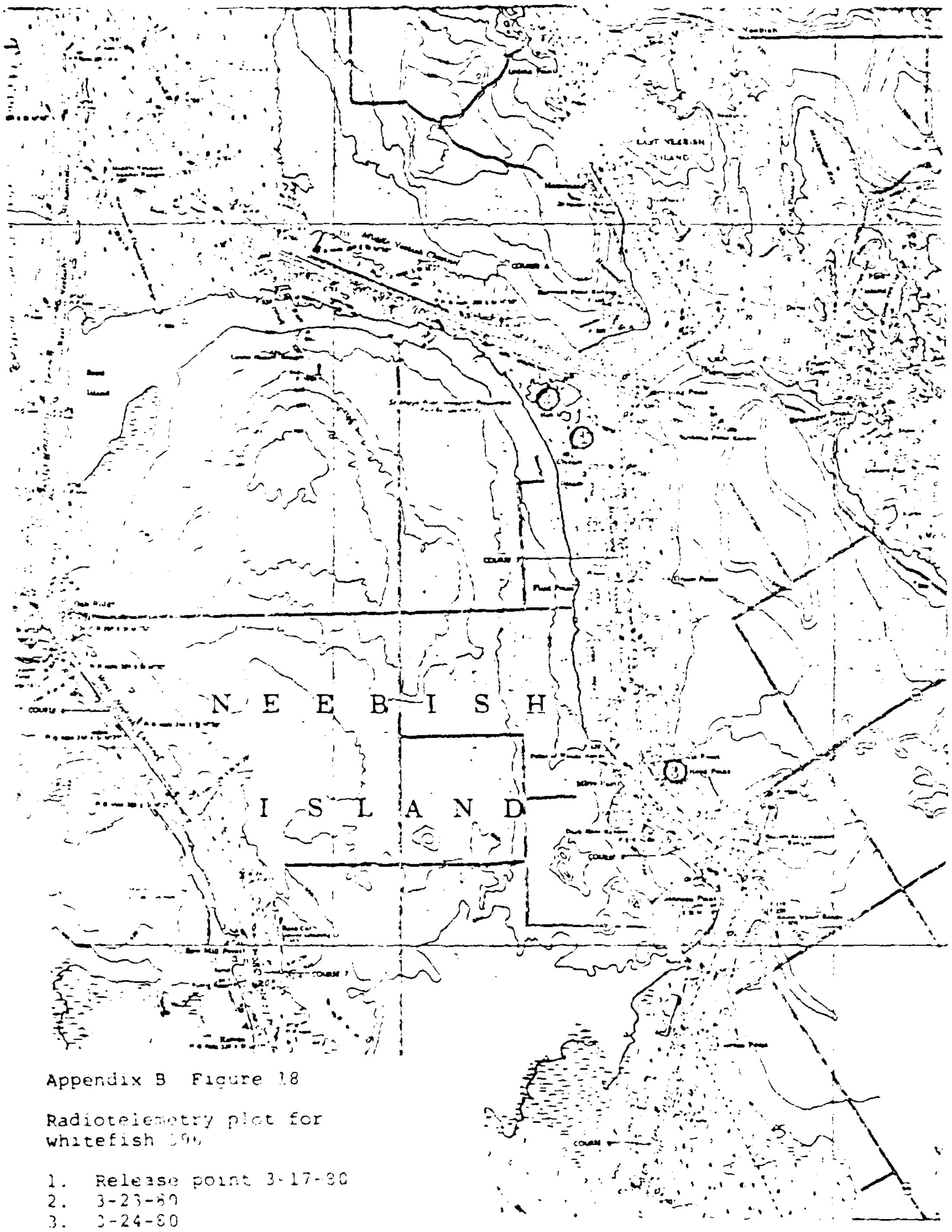
1. Release point 2-22-80
2. 2-26-80
3. 2-27-80
4. 2-28-80
5. 3-5-80
6. 3-9-80
7. 3-15-80
8. 3-21-80
9. 3-24-80



Appendix B Figure 17

Radiotelemetry plot for northern pike 332

1. Release point 3-19-80
2. 3-23-80
3. 3-24-80



Appendix B Figure 18

Radiotelemetry plot for whitefish 390

1. Release point 3-17-80
2. 3-23-80
3. 3-24-80

APPENDIX C

ANNOTATED BIBLIOGRAPHY ON WINTER FISH AND MACROBENTHOS COMMUNITIES OF ST. MARYS RIVER, LAKE SUPERIOR AND LAKE HURON

ANNOTATED BIBLIOGRAPHY ON WINTER FISH AND MACROBENTHOS COMMUNITIES OF ST. MARYS RIVER LAKE SUPERIOR AND LAKE HURON

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OVERVIEW

One component of the U.S. Army Corps of Engineers' proposal to extend the Great Lakes - St. Lawrence Seaway winter navigation program is the installation of five air bubbler systems in the St. Marys River and Whitefish Bay, Lake Superior. NUS Corporation contracted with the U.S. Fish and Wildlife Service for a study to investigate, through field and literature studies, the potential effects of the bubbler systems on fishes and aquatic invertebrates.

One component of the study is the development of an annotated bibliography which would be of value in determining winter species composition, distribution and abundance of fishes and benthic macroinvertebrates in the study area. Assuming that highly specific information would be limited, the scope of this task includes documentation of information from other areas of the upper Great Lakes. Since ice cover studies have been relatively limited, the bibliography has incorporated many other types of studies which provide some information on winter occurrence, e.g. spawning and development, seasonal movement, commercial fishery statistics, and creel census.

ANNOTATED BIBLIOGRAPHY

Anderson, E. D. and L. L. Smith, Jr. 1971. Factors affecting abundance of lake herring (Coregonus artedii Lesueur) in western Lake Superior. Trans. Am. Fish. Soc. 100(4):691-707.

A field and laboratory study conducted in 1965-1968 investigated factors affecting lake herring abundance in western Lake Superior. In the Apostle Islands area, herring eggs were more abundant and viable, and larvae were more abundant but smaller than in the Duluth-Superior area. Competition for food at the critical larval stage was likely the major influence in the lake herring decline.

The lake herring fishery was conducted primarily in the November-December spawning season. Eggs were most abundant at that time, less abundant in April, and hatched in April and May. Bloater eggs typically hatched in June and July. Herring larvae were most abundant in late May and early June.

Applegate, V. C. 1961. Downstream movement of lampreys and fishes in the Carp Lake River, Michigan. U.S. Fish and Wildlife Service Spec. Sci. Rep.-Fish. 387, 71 pp.

An inclined-screen trap was used to sample fish throughout the year in Carp Lake River, Emmett County, 1948-1958. Catch data were presented for sea lamprey, American brook lamprey, silver lamprey and 22 other species. Downstream movement in winter was evident in lampreys, grass pickerel, white sucker, northern pike, common shiner, yellow perch, central mudminnow and some other species.

Bailey, M. M. 1964. Age, growth, maturity and sex composition of the American smelt, Osmerus mordax (Mitchill), of western Lake Superior. Trans. Am. Fish. Soc. 93(4):382-395.

January-March samples of smelt were collected in 1-and 1½-inch-mesh gill nets, usually on the bottom. Gill nets, trawls, seines, weir traps, pound nets and a shocker were used other months.

Bailey, M. M. 1972. Age, growth, reproduction and food of the burbot, Lota lota (Linnaeus), in southwestern Lake Superior. Trans Am. Fish. Soc. 101(4):667-674.

Burbot samples were collected in April - December in gill nets and otter trawls, and in January-March in gill nets fished under the ice. Burbot collected near shore in late January and February were spent, but none collected offshore during January and March had spawned.

Behmer, D. J. and G. R. Gleason. 1975. Winter fish movement at a proposed bubbler site, St. Marys River system. Lake Superior State College, Sault Ste. Marie, Mich. 31 pp.

Two Vexilar Sonagrafs were used to record fish movements under the ice on March 5-16, 1975, at the edge of the shipping channel near Barbeau. The majority of the fish swam downstream in a southeasterly direction. Fish moved mostly at dawn, during the late afternoon, and at night. Data on summer and fall gill net catches were given.

Budd, J. 1957. Movements of tagged whitefish in northern Lake Huron and Georgian Bay. Trans. Am. Fish. Soc. 86:128-134.

Tagged whitefish left South Bay in early summer, and spent the remainder of the year outside and returned the following spring. A major migration route east into Georgian Bay was evident.

Buettner, H. J. 1961. Recoveries of tagged, hatchery-reared lake trout from Lake Superior. Trans. Am. Fish. Soc. 90(4):404-412.

Lake trout were tagged and released at Pendills Creek, Whitefish Bay. Mean distance between points of planting and recovery increased with time after release. More than half of the recoveries after over two years were made within 25 miles from point of release.

Carr, I. A. 1962. Distribution and seasonal movements of Saginaw Bay fishes. U.S. Fish and Wildlife Serv. Spec. Sci. Rep. Fish. 417:1-13.

Collections from the M/V *Cisco* in Saginaw Bay yielded 47 species. Young alewives were collected in shallow water in September and October, and some in deep water in October. Older alewives were most abundant in shallow spawning areas in August.

Young-of-the-year smelt were plentiful in shallow water after July and in deep water in October. Good catches of older smelt were made in shallow water in June and October and in deep water in August.

Substantial numbers of larger perch were caught in shallow waters June-November and in deep water in October. Many young were caught in shallow water in October.

Chubs (*Coregonus* spp.) were taken almost exclusively by gill nets in the deep outer bay. Lake herring were not concentrated until the spawning run in mid-November.

White suckers inhabitated mostly shallow water but some occurred to a depth of 98 ft.

Cook, D. G. 1975. A preliminary report on the benthic macroinvertebrates of Lake Superior. Canada Center for Inland Waters, Fisheries and Marine Service Tech. Rep. 572. 44pp. (Burlington).

The benthos of Whitefish Bay was described from May, 1973 samples from a mean depth of 65m. Mean abundance (3000/m^2) was about six times the lakewide average, while biomass was nearly ten times the lakewide value. Taxonomic representation was 29% *Pontoporeia affinis*, 38% oligochaetes, 5% nematodes, 23% sphaeriids, and 5% chironomids.

Dryer, W. R. 1964. Movements, growth and rate of recapture of whitefish tagged in the Apostle Islands area of Lake Superior. U.S. Fish. Bull. 63(3):611-618.

Movements of whitefish tagged in the Apostle Islands region were studied. Seasonal movements were relatively restricted providing evidence of a fairly discrete or sedimentary population.

Dryer, W. R. 1966. Bathymetric distribution of fish in the Apostle Islands region, Lake Superior. Trans. Am. Fish. Soc. 95(3):248-259.

Fish were sampled during April - December, thus providing minimal information on winter distribution.

Dryer, W. R. and J. Beil. 1964. Life history of lake herring in Lake Superior. U. S. Fish. Bull 63:493-530.

Lake Herring became aggregated in very dense schools in shallow inshore waters or on offshore banks, preparatory to spawning, in late autumn and early winter.

Dryer, W. R. and J. Beil. 1968. Growth changes of the bloater (*Coregonus hoyi*) of the Apostle Islands region of Lake Superior. Trans. Am. Fish. Soc. 97(2): 146-158.

Most bloater spawning occurred in February and March, and some ripe bloaters were caught in all months. Spent and ripe bloaters occurred at 20-50 fathoms during February and March.

Dryer, W. R., L. F. Erkkila, and C. L. Telzloff. 1965. Food of lake trout in Lake Superior. Trans. Am. Fish. Soc. 94(2):169-176.

Lake trout were collected commercially and experimentally throughout the year in Lake Superior. Winter samples were from depths of 2-70 fathoms. The occurrence of *Coregonus* in stomachs increased from 35% in February - March to 71% in October - December. Smelt were in 77% of the stomachs February - March. Fish were the major food of larger lake trout.

Eschmeyer, P. H. 1955. The reproduction of lake trout in southern Lake Superior. Trans. Am. Fish. Soc. 84(1954):47-74.

Of fish recaptured during subsequent spawning seasons, most were taken near the spawning area. Most spawning was in October and November at less than 20 fathoms. Some spawning may have occurred during June-September.

Eschmeyer, P. H., R. Daly, L. F. Erkkila. 1953. The movement of tagged lake trout in Lake Superior, 1950-1952. Trans Am. Fish. Soc. 82(1952):68-77.

Mature fish tagged on spawning grounds dispersed widely but most returned in subsequent spawning seasons.

Faber, D. J. 1970. Ecological observations on newly hatched lake whitefish in South Bay, Lake Huron. pp 481-500. In C. C. Lindsey and C. S. Woods (eds), Biology of coregonid fishes, Univ. of Manitoba Press, Winnipeg.

Whitefish spawned in mid-November. The winter incubation period in the northern Great Lakes was about 168 days. Larvae were most abundant at 4C, between the third week of April and third week of May. Associated larvae included the burbot, lake herring, deepwater sculpin, and rainbow smelt.

Fry, F. E. J. 1953. The 1944 year class of lake trout in South Bay, Lake Huron. Trans. Am. Fish. Soc. 82(1952):178-192.

All tagged lake trout released remained within South Bay, Lake Huron.

Gleason, G. R. and D. J. Behmer. 1975. Navigation and winter recreation. Lake Superior State College, Sault Ste. Marie. Mich. Bur. Outdoor Rec. Contract No. 5-14-07-2. 60 pp.

The Upper St. Marys River, from Mosquito Bay to Leighs Bay, produced a good whitefish fishery in January and a yellow perch fishery in the winter. In Lake Nicolet there were productive yellow perch and walleye fishing areas. Fishing was limited around Neebish Island. Lake Munuscong was noted for walleye and yellow perch fishing in winter and spring. The lower river has produced significant fisheries for herring, yellow perch, northern pike and walleye.

Whitefish Bay was one of the best lake trout fishing areas in the U.S. Average fishing depth was 130-180 ft. Peak winter fishing was in February and March.

Yellow perch and coho salmon were caught in Whitefish Bay tributaries. Whitefish and herring were speared from ice shanties in the Leighs Bay area. Northern pike were speared in Lake Nicolet.

Results of the creel survey are summarized in Table 1 (this report).

Gleason, G. R., D. J. Behmer, and K. L. Vincent. 1979. Evaluation of benthic dislocation due to pressure waves initiated by vessel passage in the St. Marys River. Report for Project Number 5100, Great Lakes Basin Comm. for Environmental Evaluation Work Group of Winter Navigation Board. 64 pp.

Ships navigating ice covered connecting channels in the Upper Great Lakes frequently reach a critical speed which creates a pressure fracture line near the shore. The sudden pressure release due to the fracture displaces water, sediments and incumbent benthos to the ice surface. The object of this study was to determine if the loss and environmental disruption was significant to the total estimated benthic population at selected sites in the St. Marys River.

Three stations established on the St. Marys River between Frechette and Six Mile points were sampled during the winter of 1978-79. Sampling parameters included benthic, ice surface deposits and ice movement due

to vessel passage. Twenty-four ships monitored provided 11 samples of which 5 contained benthic organisms.

The 1978-79 extended shipping season did not produce a significant loss of benthos to the ice surface. It was found that for a one meter length of crack approximately 10 organisms were displaced per vessel passage, or 0.1% of the existing benthic population below the sample sites. Dominant benthic groups were Oligochaeta, Gastropoda, Pelecypoda and subfamilies of Chironomidae.

Gleason, G. R., D. J. Behmer, and R. Hook. 1979. Evaluation of lake whitefish and herring spawning grounds as they may be affected by excessive sedimentation induced by vessel entrapment due to the ice environment within the St. Marys River system. Lake Superior State College, Sault Ste. Marie, Mich. 37 pp.

The St. Marys River (connecting channel between Lake Superior and Lake Huron) has historically been associated with the harvesting of coregonines during late fall spawning. Winter navigation and its associated activities could have deleterious effects on the incubating eggs, including excessive sedimentation, localized current alterations, and dislocation of eggs due to vessel induced pressure response.

A study starting in February of 1979 attempted to locate the spawning ground of the lake whitefish and lake herring and to determine the amount and classification of sediments deposited over these spawning grounds. Proportionately larger amounts of sediments were collected over those identified spawning grounds adjacent to the shipping channel as opposed to sites remote from the shipping channel. Seven reported spawning sites were sampled. Attempts to recover eggs of the above species from the spawning ground were unsuccessful.

The r[illegible] whitefish, or menominee, and the burbot have spawning requirements similar to the herring and lake whitefish.

Hart, J. C. 1930. The spawning and early life history of the whitefish, Coregonus clupeaformis (Mitchill) in the Bay of Quinte, Ontario. Contrib. Can. Biol. Fish. 6(7):167-214.

Hart studied the spawning, egg survival and early life history in the Bay of Quinte. Whitefish migrate to shallow spawning areas in the fall. Whitefish eggs are slightly more dense than water and are randomly scattered. Mortality of eggs exceeded 90% during the winter incubation.

Hile, R., G. F. Lunger, and H. J. Buettner. 1953. Fluctuations in the fisheries of State of Michigan waters of Green Bay. U.S. Fish. Bull. 54:1-34.

Seasonal production of Green Bay fisheries and types of gear used prior to 1951 were described. After 1944, the shallow trap net was the most important gear, followed by large-mesh gill nets.

Hiltunen, J. K. 1979. Investigation of macrobenthos in the St. Marys River during an experiment to extend navigation through winter, 1974-75. USFWS, Great Lakes Fishery Lab., Ann Arbor, Mich. 24 p. + app.

The Great Lakes Fishery Laboratory conducted a Corps-funded study of the macrobenthos in the Lake Nicolet portion of the St. Marys River to ascertain what, if any, harmful effects could be attributed to pressure waves (drawdown and surge) generated by ships coursing through heavy ice. Analysis of 168 macrozoobenthos samples collected at 15 stations in Lake Nicolet before ice formation (October 1974), during ice cover (January-February 1975), during ice breakup (April 1975), and following ice breakup (May 1975), revealed that the lake supports a rich and diverse fauna, with oligochaetes and immature insects, including midge larvae, mayfly nymphs, and caddisfly larvae being the most abundant forms. Taxa are listed in enclosed Table 2).

No significant decline in population densities of any macrozoobenthos or macrophytes in either the test or control areas was evident following the winter navigation experiment. Therefore, effect on the macrobenthos of pressure waves generated by passage of vessels through ice, during the demonstration, could not be shown at the stations.

Koelz, W. 1929. Coregonid fishes of the Great Lakes. U.S. Fish. Bull. 43:295-643.

This paper reviews the literature on coregonids of the Great Lakes. In Lake Superior, lake herring came ashore toward the end of October and remained until ice formed in early December, at 3-4 fathoms. Whitefish probably remained on shoals under the ice but were driven off by winds when the ice broke up. Bloaters spawned in February and March.

Lawrie, A. H. and J. F. Rahrer. 1973. Lake Superior, a case history of the lake and its fisheries. Great Lakes Fishery Comm. Tech. Rep. No. 19. 69 pp.

This report presents a general review of Lake Superior with emphasis on its fish stocks. Lake trout ranged in depth from tributaries to over 183m. Lake trout movement studies were reviewed. Lake whitefish were restricted to inshore habitats, mostly at less than 53m.

Five species of chubs occurred in deep waters and the closely-related lake herring, in shallow waters. Lake herring aggregated in inshore waters during late autumn and early winter, preparatory to spawning. Walleye were largely absent from the open lake but supported local fisheries in large bays and island regions. Spawning months and depths (m) of Lake Superior *Coregonus* species are as follows: *C. artedii* (mostly Nov. - Dec., 15-128), *C. hoyi* (mostly Feb. - Apr., 37-92), *C. nigripinnis* (Sept.-Oct., 110-183), *C. zenithicus* (Nov.-Dec., 18-55), *C. kiyi* (Nov.-Dec.), *C. reighardi* (May-June, 37-145).

Loftus, K. H. 1958. Studies on river-spawning populations of lake trout in eastern Lake Superior. Trans. Am. Fish. Soc. 87 (1957):259-277.

All stream recoveries of river-spawning trout were in the stream of release.

MacDonald, G. A. 1977. The Saulteur-Ojibwa fishery at Sault Ste. Marie, 1640-1920. M. A. Thesis, Univ. of Waterloo, Waterloo, Ontario, 211 pp.

This thesis describes the history of the Saulteur-Ojibwa fishery and provides observations on the life history of commercial species. Lake whitefish and lake herring spawned in lower St. Marys River. Some of these spawning grounds were confined to the southern portions of Lake Nicolet and the northern portions of Lake Munuscong.

Macnniak, K. 1975. The effects of hydroelectric development on the biology of northern fishes (Reproduction and population dynamic) I. Lake whitefish Coregonus clupeaformis (Mitchill). A literature review and bibliography. Dept. Envir., Fish., and Mar. Serv. Tech. Rep. 527. 67 p. (Winnepeg).

Whitefish and lake herring spawned in late October, November, and early December. Whitefish normally spawn over gravel and/or rubble bottoms at 1 to 5 m depths. Other substrates and depths may be used. Egg predation by fishes was a major source of mortality.

Moore, H. H. and R. A. Braem. 1965. Distribution of fishes in U.S. streams tributary to Lake Superior. U.S. Fish and Wildlife Service Spec. Sci. Rep. Fish. 516, 61 pp.

Seventy-one fish species were recorded from 175 streams. Information on seasonal occurrence was not presented.

National Biocentric, Inc. 1973. Environmental review report for demonstration of bubbler system in the Superior Entry, Duluth - Superior Harbor. U.S. Army Corps of Engineers, St. Paul Minnesota. 108 pp.

Benthic samples were collected with a nine inch Petersen-Ponar dredge in November and a six inch Ekman dredge in January. Lumbriculus inconstans was the predominant species. Results suggested that bubbler operation was favorable for benthic organisms.

Fish were not studied. Anoxic conditions in winter limited the fish community to yellow perch, carp and some minnows. Smelt, steelhead, walleyes and northern pike moved into the area in spring.

Poe, T. P., T. A. Edsall, and J. K. Hiltunen. 1979. Effects of ship-induced waves in an ice environment on the St. Marys River ecosystem. U.S. Fish and Wildlife Service, Ann Arbor, Mich. 24pp + app.

Sampling was conducted at Frechette Point and Six Mile Point in the St. Marys River during January 16-20, February 13-19, and March 13-18, when there was solid ice cover, and during April 17-21, immediately after the solid ice cover had been broken up by heavy vessel traffic.

Macroinvertebrates of 56 taxa were identified in 75 Ponar samples. The most abundant organisms were Chronomidae (midge larvae), Oligochaeta (worms), and Gastropoda (snails); collectively they comprised about 67% of the total number of organisms collected. Pelecypoda (fingernail clams), Amphipoda (scuds), Polychaeta, Ephemeroptera (mayflies), and Trichoptera (caddisflies) were common in all samples and collectively made up about 22% of the total. The density of benthic macroinvertebrates (all taxa combined) for all stations and months was 14,125.8/m^2 (A list of taxa is presented in enclosed Table 3).

Drift nets fished 98 times at Frechette Point and Six Mile Point captured macroinvetebrates representing 24 taxa, aquatic macrophytes (Elodea), detritus, planktonic microcrustacea, and fish, but no fish eggs. Examination of the drift net fishing records and the records of vessel passages through the study area revealed a large increase in the amount of drift occurred as a result of vessel passages during the period of solid ice cover. Comparison of drift net catches in March when there was solid ice cover and moderate vessel traffic with catches in April when there was heavy floe ice and very heavy vessel traffic suggests the effect of vessel passage on drift was greater when solid ice cover was present.

A total of 73 fish representing seven species was caught in gill nets, fyke nets, and traps during January-April. White suckers dominated the catch (76.7%), followed by burbot and sculpin (each at 6.8%); other species taken included yellow perch, lake herring, northern pike, longnose sucker, and ninespine stickleback. Too few fish were collected to determine if vessel passage affected fish distribution or abundance in the study area. The burbot was the only winter-spawning fish collected in the study area.

Price, J. W. 1940. Time temperature relations in the incubation of the whitefish Coregonus clupeaformis (Mitchill). J. Gen. Physiol. 23:449-468.

Whitefish eggs have a long winter incubation period. Optimum incubation temperature for whitefish eggs is about 0.5°C.

Pycha, R. L. 1961. Recent changes in the walleye fishery of northern Green Bay and history of the 1943 year class. Trans. Am. Fish. Soc. 90(4):475-488.

The walleye fishery fluctuated widely in Green Bay in 1929-1957. Walleyes were collected in two periods, referenced as spring (January-June) and fall (August-December). Commercial gear included pound nets, shallow trap nets, fyke nets, hoop nets, and gill nets.

Pycha, R. L., W. R. Dryer and G. R. King. 1965. Movements of hatchery-reared lake trout in Lake Superior. J. Fish. Res. Board Can. 22(4):999-1024.

The history of stocking of lake trout in the Great Lakes was reviewed. Yearling trout were planted mostly in the spring, others in the fall. The highest abundance was in areas 2-4 miles from the planting site even three years after release. Most movement was eastward and followed counterclockwise surface currents.

Rahrer, J. F. 1968. Movements of adult lake trout in Lake Superior. Trans. Am. Fish. Soc. 97(4):481-486.

Most tagged lake trout remained in the area of spawning in November. They dispersed December through March and returned toward the spawning ground in August and September.

Reckahn, J. A. 1970. Ecology of young lake whitefish (Coregonus clupeaformis) in South Bay, Manitoulin Island, Lake Huron, pp. 437-450. In C. C. Lindsey and C. S. Woods (eds), Biology of Coregonid Fishes. Univ. of Manitoba Press (Winnepeg).

Whitefish spawned over rocky shoals in a bay of Lake Huron. Young occurred in shallow waters of the bay at 17°C and near vegetation. As temperatures decreased, the fish moved into the metalimnion for 6-8 weeks (July, August) and then into deeper water in the winter.

Rosa, S. 1979. Preliminary attempts in locating lake whitefish (Coregonus clupeaformis) spawning ground by winter egg collection in areas of upper St. Marys River. Ontario Min. Nat. Res. Unpub. Rep. 8p. + app. (Sault Ste. Marie).

A pump and Ekman dredge were used to locate whitefish spawning sites by sampling for eggs near the source of the St. Marys River. Late February and March samples produced one coregonine egg near the Big Carp River and five near Point des Chenes.

Spangler, G. R. 1970. Factors of mortality in an exploited population of whitefish, Coregonus clupeaformis, in northern Lake Huron, pp. 515-529. In C. C. Lindsey and C. S. Woods (eds), Biology of Coregonid Fishes. Univ. of Manitoba Press (Winnipeg).

Specimens were taken with 114 m nylon gill nets from April to June and late September to late November. Fall fishing was at 3-9 m. Tag recoveries after one or more years indicated a reasonably discrete population with seasonal inshore/offshore movements.

Spangler, G. R. 1970. Mortality factors and dynamics of a Lake Huron lake whitefish population. Ph.D. thesis, Univ. of Toronto (Canada) (see reference above).

Sydor, M., B. O. Krogstad, and T. O. Odlaug. 1974. Evaluation of bubbler system for winter navigation, Howards Bay, Superior, Wisconsin, winter 1973-74. University of Minnesota, Duluth. U.S. Army Corps of Engineers, St. Paul District Office, Minnesota. 59 p. + app.

Benthos was collected with a Peterson dredge in the winter. Substrate ranged from fibers and wood chips to clay with small rocks. Organism abundance ranged from 11 to over 450 per liter of sediment. Tubificids represented the great bulk of the macrobenthos. Limnodrilus (probably hoffmeisteri) was the dominant species.

U.S. Army Engineer District, Detroit. 1979. Survey study for Great Lakes and St. Lawrence Seaway Navigation Season Extension, Draft Main Report and Environmental Statement. Detroit, Michigan.

Potential effects on fish were discussed in the Draft Environmental Report. Lake herring and whitefish in Lake Superior spawned November-December. Incubation was about 150 days at 34 F. Some eggs may occur near the navigation channel.

The burbot spawned November-May, over sandy or gravel bottom, at 1-4 ft deep. Gravel shoals at 5-10 ft have also been used for spawning. Young appeared in about 30 days, generally from late February to June.

Spawning migrations of lake sturgeon generally occur when rivers are ice-free but have been noted under ice. The sturgeon generally spawns at 2-5 ft deep from early May to late June.

It has been theorized that long-line bubblers could interfere with fish migration should some species refuse to cross the air curtain.

Recommendations of the U.S. Fish and Wildlife Service are included.

United States Fish and Wildlife Service. 1969. Fish and wildlife as related to water quality of the Lake Huron Basin. Report to U.S. Dept. Interior, Federal Water Pollution Control Adm. 133pp.

This is a report on the effects of water quality upon the fish and wildlife of the Lake Huron Basin. Little information on winter distribution of aquatic biota was presented. Most of the fyke net fishing has been carried on in the Saginaw River through the ice, and principal species taken were yellow perch, suckers and catfish. Fishing through the ice for panfish was a popular sport. "Dark houses" were popular for spearing sturgeon and northern pike.

United States Fish and Wildlife Service. 1970. Fish and wildlife as related to water quality of the Lake Superior Basin. Report to U.S. Dept. of Interior, Federal Water Quality Adm. 149 pp.

This is a report on the effects of water quality upon fish and wildlife in the Lake Superior Basin. Little information on winter distribution of aquatic biota was included. Herring were commercially caught every month of the year, with a peak during October-December. Rainbow smelt fishing was popular at mouths of streams in early spring.

United States Fish and Wildlife Service, Ann Arbor, Michigan (pers. comm.).

Data on commercial production in pounds by month for lakes Superior and Huron were compiled for 1976, 1977 and 1978. Fish were collected predominantly with gill nets under the ice during January, February and March. The catch for these months in Michigan waters of Lake Huron was predominantly carp, yellow perch, suckers, and bullheads. The winter catch in Michigan waters of Lake Superior was predominantly chubs, whitefish, lake herring, burbot and lake trout.

United States Fish and Wildlife Service, East Lansing, Michigan (pers. comm).

Staff of the U.S. Fish and Wildlife Service (East Lansing, Michigan) sampled fish and macrobenthos in the winter of 1978-1979 in the middle and west channels of St. Marys River, Neebish Island. Gill nets and hoop nets were used. Northern pike, white sucker, walleye and burbot were tracked with radio telemetry.

Veal, D. M. 1968. Biological survey of the St. Marys River. Ontario Min. Environment, Water Resources Comm. 23 pp. + app.

Summer sampling was undertaken to describe effects of pollution on benthic macroinvertebrates of St Marys River. Wastes from Canadian industries did not disrupt invertebrate populations on the American side of the river. Densities of macroinvertebrate taxa were presented in the appendix.

Wohlgemuth, O. 1978. Investigations of whitefish spawning areas, Marks and Leighs Bays, St. Marys River, Sault Ste. Marie District. Ontario Min. Nat. Res. Unpub. Rep. 5p + app. (Sault Ste. Marie).

A large number of whitefish in spawning condition were collected near the source of the St. Marys River, from October 26 to November 9, at 0.5-3 fathoms. This area was considered to be an important spawning ground for whitefish. The catch included white suckers (31%), northern pike (2%), yellow perch, salmonids, herring, rock bass, menominee, burbot and carp.

TABLE 1

WINTER SPORT FISH CATCH AT STATIONS IN THE ST. MARYS RIVER/WHITEFISH BAY AREA, 1975. (GLEASON AND BEHMER 1975)

Station	Species	Average Catch Per Person-Hour
Shallows	Lake whitefish	.0433
	Menominee	.0097
	Herring	.0032
Pumping Station	Lake whitefish	.0751
Penuiii's	Coho	.0326
Silver Creek	Lake whitefish	.0593
Cole's	Walleye	.0425
	Perch	.0074
	Pike	.0054
Raber	Perch	.1206
Methodist	Perch	.0488
Dan's	Walleye	.0405
	Perch	.0109
	Pike	.0111

TABLE 2

MACROINVERTEBRTE TAXA OF LAKE NICOLET, ST. MARYS RIVER, OCTOBER 1974 TO MAY 1975. (HILTUNEN 1979).

Porifera (sponges)
- *Spongilla*

Cnidaria (hydras)
- *Hydra*

Turbellaria (flat worms)
- Rhabdocoela
- Tricladida

Nemertinea (proboscis worms)

Nemata (roundworms)

Bryozoa (moss animalcules)

Hirudinea (leeches)
- Batracobdellidae
- Erpobdellidae
- Glossiphoniidae
- Pisciolidae

Oligochaeta (segmented worms)
- Enchytraeidae
- Glossoscolecidae
- Lumbriculidae
- Naididae
- Tubificidae

Polychaeta
- *Manayunkia speciosa* (feather-duster worm)

Amphipoda (amphipods)
- *Crangonyx*
- *Gammarus*
- *Hyalella azteca*
- *Pontoporeia hoyi*

Cladocera (cladocerans)
- *Eurycercus lamellatus*

Decapoda (crayfish)
- *Orconectes*

Ostracoda (ostracods)

Isopoda (sowbugs)
- *Asellus*
- *Lirceus*

Insecta
- Coleoptera (beetles)
  - Elmidae
  - Haliplidae
  - Hydrophilidae
  - Noteridae
- Diptera
  - Ceratopogonidae (biting midges)
  - Chaoboridae (phantom midges)
  - Chironomidae (midges)
  - Empididae (dance flies)
- Ephemeroptera (mayflies)
  - Baetidae
  - Baetiscidae
  - Caenidae
  - Ephemerellidae
  - Ephemeridae
  - Heptageniidae
  - Leptophlebiidae
- Hemiptera
  - Corixidae (water boatmen)
- Lepidoptera (moths)
- Neuroptera
  - Sialidae (alderflies)
  - Sisyridae (spongillaflies)
- Odonata
  - Coenagrionidae (damselflies)
- Trichoptera (caddisflies)
  - Helicopsychidae
  - Hydroptilidae
  - Lepidostomatidae
  - Leptoceridae
  - Limnephilidae
  - Molannidae
  - Phryganeidae
  - Polycentropodidae
  - Psychomyiidae

Acarina (water mites)

Gastropoda (snails)

Pelecypoda
- Sphaeriidae (fingernail clams)
  - *Pisidium*
  - *Sphaerium*
- Unionidae (mussels)

TABLE 3

BENTHIC MACROINVERTEBRATES COLLECTED BY PONAR GRAB FROM THE ST. MARYS RIVER FRECHETTE POINT AND SIX MILE POINT, JANUARY-APRIL 1979 [F = FOUND ONLY AT FRECHETTE POINT: S = FOUND ONLY AT SIX MILE POINT] (POE ET AL. 1979).

Cnidaria
- Hydra

Tricladida

Rhabdocoela

Nematoda

Nemertinea (S)

Hirudinea

Oligochaeta

Polychaeta
- Manayunkia speciosa

Copepoda

Decapoda
- Orconectes (F)

Ostracoda

Amphipoda
- Gammarus
- Hyalella azeteca

Isopoda
- Asellus
- Lirceus

Diptera
- Tripulidae (S)
- Ceratopogonidae
- Chironomidae
- Empididae
- Simulidae

Ephemeroptera
- Ephemerella
- Baetisca (F)
- Caenis
- Ephemera
- Hexagenia

Coleoptera
- Haliplus (S)
- Dytiscidae (S)

Lepidoptera

Neuroptera
- Sialis (F)

Trichoptera
- Mystacides
- Triaenodes
- Cheumatopsyche
- Hydropsyche (F)
- Neureclipsis (F)
- Polycentropus
- Agrypnia
- Ceraclea (F)
- Hydroptila
- Setodes (F)
- Molanna
- Oecetis
- Phylocentropus
- Psycomyia (F)

Hemiptera
- Corixidae (S)

Acarina
- Arrenurus

Gastropoda
- Amnicola
- Campeloma
- Gyraulus
- Helisoma
- Lymnaea
- Physa
- Valvata sincera
- V. tricarinata
- Goniobasis livescens

Pelecypoda
- Pisidium
- Sphaerium

APPENDIX D

ECOLOGICAL EFFECTS OF AIR BUBBLERS IN THE WINTER, A PARTIALLY ANNOTATED BIBLIOGRAPHY

ECOLOGICAL EFFECTS OF AIR BUBBLERS IN THE WINTER
A PARTIALLY ANNOTATED BIBLIOGRAPHY

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OVERVIEW

One component of the U.S. Army Corps of Engineers' proposal to extend the Great Lakes-St. Lawrence Seaway winter navigation program is the installation of five air bubbler systems in the St. Marys River and Whitefish Bay, Lake Superior. NUS Corporation contracted with the U.S. Fish and Wildlife Service for a study to investigate, through field and literature studies, the potential effects of the bubble systems on the fish and aquatic invertebrates. One component of the study is an annotated bibliography covering ecological effects of air bubble systems in the winter. The scope of the bibliography was expanded to include listing, predominantly without summaries, of papers on the design and operation of winter bubble systems.

Air bubbling systems have been used extensively in the winter to reduce ice cover and prevent winterkill of fish. Excluded from this bibliography is the extensive literature on the use of air bubbling to enhance water quality of ice-free waters through aeration and destratification. This information would not be highly relevant to the objective because of major seasonal differences in limnological conditions and limited destratification effects in the winter. For information on destratification, the reader may refer to Symons (1969), Boyd (1979), Toetz et al. (1972), Fast (1971), Lorenzen and Fast (1977), King (1970), and Environmental Quality Laboratory, Inc. (1977) (all cited in this bibliography) and other reports.

With the exception of winterkill studies, which are restricted to small water bodies, investigators have found that the effects of air bubblers on aquatic biota in the winter are minimal or very elusive. Abstracts are given for the more important studies and reviews in this bibliography. The vast majority of the references cited describe the design, operation, and effectiveness of air bubblers for reduction of ice cover. Many of the references cited are foreign and were translated with various degrees of success.

BIBLIOGRPHY

Ahbin, K. 1954. Ice-free channels with use of compressed air. Swedish Waterways J. 15(2):76.

Alevras, R. A. 1973. Status of air bubble fish protection system at Indian Point Station on the Hudson River, pp. 289-291. In L. D. Jensen (ed.) Proc. Second Entrainment and Intake Screening Workshop, Baltimore, Maryland.

Various types of air bubbler systems were evaluated t clude fish from the power plant intake. It was tentatively conc ded that the air curtain did not appear to repel fish and may attract fish during hours of darkness.

Anonymous. 1928. Counteracting the bottom ice by use of compressed air. Electrical World 91(3):140.

Anonymous. 1951. Use of compressed air as a means to counteract ice formation at dam gates. Moscow Planning Office of Gidromontazh, Survey No. 4, 10/51.

Anonymous. 1951. Air bubbles keep sawmill log pond free of ice. Ingersoll-Rand Co. Stationary Compressor Manual (September 1).

Anonymous. 1953. Compressed air keeps pond clear of ice in very cold weather. Public Works Mag. 84(4):84-86.

Anonymous. 1953. Use of compresed air to keep waterways ice-free. Polar Record 6(45):690-691.

Anonymous. 1953. Report on testing of experimental nozzle of air-blowing device for upkeep of open places at dam gates. Moscow Office of Gidrostral' proyekt.

Anonymous. 1956. Freeing navigation lanes from ice. Dock and Harbor Auth., XI. 37(433).

Anonymous. 1956. Air bubbles will keep ports open. Compressed Air Mag., No. 61:34.

Anonymous. 1956. Compressed air keeps dam free of ice. Roads and Engineering Constr. Vol. 94.

Anonymous. 1956. Compressed air keeps Winnipeg hydroelectric dam free of ice. Roads and Engineering Constr. Vol. 94:131-132.

Anonymous. 1956. Air bubbles keep ports open; scheme to utilize compressed air to maintain an ice-free shipping lane in Lake Malar. Compressed Air Mag. Vol. 61, p. 347; Midwest Eng., Vol. 9, p. 32.

Anonymous. 1957. Report on experimental research into operation of test installation of air blowing unit. Moscow Office of Gidrostal'proyekt.

Anonymous. 1957. De-icing system proves successful at the St. Lawrence River dock. Roads and Engineering Constr. 95(5):120,149.

Anonymous. 1957. Air bubbles battle king winter. Compressed Air Mag. Vol. 62:84.

Anonymous. 1957. Idea for melting ice; air bubbles pumped to surface thaws Arctic lake. Eng. News Record, Vol. 158:66.

Anonymous. 1957. Bubbles eliminate ice from log ponds. Timber of Canada 18(4):44.

Anonymous. 1958. Aeration permits water work at -30°F. Eng. News Record 160(14):52.

Anonymous. 1958. Novel anti-icing scheme kept bridge job going: Aeration pipe prevents ice from forming. Roads and Streets 101(4):106.

Anonymous. 1960. Can bubble machine keep seaway open? The Toronto Daily Star, January 22, p. 25.

Anonymous. 1961. Summary of reports received on air bubbling installations, Appendix A. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70. 15 pp. (Ottawa)

Anonymous. 1974. Little fish in a big pond. Bubble curtain keeps "fry" out of power plant intake. Compressed Air Mag. 79(1):10-11.

Arkansas Nuclear One (Russellville, Arkansas) uses an air bubble curtain to keep fish from entering the cooling water intakes. The air curtain, which is still considered experimental, is formed near the 400-foot-wide entrance to the cooling water inlet canal. Four fiber glass pipes with staggered "bubble" sections were laid across the canal entrance and weighted with cement to keep them on the bottom. Compressed air fed to the pipes escapes from hundreds of holes on the upper surface forming a bubble curtain. Compressed air is provided by efficient rotary screw-type air compressors manufactured by Ingersoll-Rand Company. The after coolers on all compressors are dual oil and air aftercoolers designed into a single package by Modine Manufacturing Company. When the power plant is fully operational, the air bubbler will operate 24 hours a day.

Anonymous. 1976. Extending the seaway season. Ship and Boat Int. 29(12):35-37.

Use of air bubblers mentioned for extension of seaway season.

Anonymous. 1978. Icebreaking cargo vessel in service. Marine Eng. Rev. (July). p. 35.

Canada's icebreaking cargo vessel, the Arctic, has a system of compressed air which ejects bubbles below the water line to reduce friction.

Anonymous. 1978. Canadian-built ice-breaking bulk-carrier Arctic. Shipbuilding and Marine Eng. Int. 101(1222):478-485.

Operation of the Arctic without icebreaker support is abetted by a 1,200 kw Wartsila air-bubble system.

Aronson, R. B. 1973. How northern Europe breaks the ice. Machine Design 45(1):18-20.

European methods for breaking ice are described, including bubbler systems and vibrations.

Ashton, G. D. Unpublished. Design of air bubbler systems to suppress ice. U.S. Army Cold Regions Res. Eng. Lab. 7 pp.

Ashton, G. D. 1974. Air bubbler system to suppress ice. U.S. Army Cold Regions Res. Eng. Lab. Spec. Rep. 210, 35 p. NTIS ADA-003 867.

Ashton, G. D. 1975. Experimental evaluation of bubbler induced heat transfer coefficients, pp. 133-142. In G. E. Frankenstein (ed.), Proc. Third Int. Symp. on Ice Problems, Hanover, NH.

Ashton, G. D. 1977. Numerical simulation of air bubbler systems. Presented at Third Can. Hydrotechnical Conf., Quebec.

Ashton, G. D. 1978. Numerical simulation of air bubbler systems. Can. J. Civ. Eng. Vol. 5:231-238.

Ashton, G. D. 1979. Point source bubbler systems to suppress ice. U.S. Army Cold Regions Res. Eng. Lab., CRREL Rep. 79-12. 12 p.

Atlas Copco. 1959. Temperature falls, bubbles rise, ice melts. Compressed Air Comments 2(1).

Bainbridge, R. 1964. The problem of excluding fish from water intakes. Annals Applied Biology, Vol. 53, pp. 505-509.

A bubble screen was tried without success around the water intake at the Uskmouth Station. A screen using a combination of stimuli would likely be more successful.

Baines, W. D. 1961. The principles of operation of bubbling systems, pp. 12-22. In Proc. Symp. on Air Bubbling. Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

Baines, W. D. and G. F. Hamilton. 1959. On the flow of water induced by a rising column of air bubbles. Proc. Eighth Congress Int. Assoc. Hydraul. Res., Paper 7-D.

Balanin, V. V. 1953. Operation of navigable sluices at reduced temperatures under conditions of extending the navigational period. Trans. Leningrad Inst. Water Transport, No. 20.

Balanin, V. V., B. S. Borodkin, and G. I. Melkonyan. 1970. Utilization of deep water heat in reservoirs for the maintenance of unfrozen water areas. U.S. Army Cold Regions Res. Eng. Lab., translation from Russian, 272 p. (NTIS AD-716 306).

The authors have pioneered in systematizing the material obtained from laboratory and full-scale studies of measures for maintaining in unfrozen condition the reservoirs with the aid of the heat from deep water; they have shown the physical character of the methods for utilizing the deep water heat. General descriptions have been given of the means for combatting ice and the basic systems of various installations; also included are the rough calculations of measures used to maintain the open reservoir basins at negative temperatures. The authors have reviewed certain questions involved in the theory of operation of pneumatic units and flow-forming devices; descriptions are given of certain designs for operational pneumatic installations in the USSR and abroad, including the experience gained in their operation, along with their advantages and disadvantages.

Bates, D. W. and J. D. Van Derwalker. 1969. Exploratory experiments on the deflection of juvenile salmon by means of water and air jets. Fish Passage Program, Review of Progress, U.S. Bur. Comm. Fish. 3(14):6, Seattle, Wash.

Exploratory studies were undertaken to determine if water jets or air bubble curtains could successfully guide and collect juvenile salmon from rivers and steams. The water jet deflector showed potential when an appropriate combination of approach velocities, angle, and jet pressure was employed. However, extensive maintenance and the need for large volumes of water made continued consideration of this technique impractical. Fish exposed to an air bubble screen deflector showed a definite response during daylight hours, but the poor deflection obtained during nighttime hours precludes its use as a functional barrier to downstream migrants.

Bates, R. E. 1976. Winter thermal structure and ice conditions on Lake Champlain, Vermont. U.S. Army Cold Regions Res. Eng. Lab. Rep. CRREL-76-13: 30 pp.

Included in this winter study were observations on the operation of a bubbler system around a service dock.

Bechtel Associates. 1970. Survey and performance of fish screening systems. Report to Consolidated Edison Co. of New York, Inc. 50 pp.

This report presents the results of a survey and review of the types of intakes and fish screening facilities that have been developed and adopted by various utilities; the performance of existing or experimental intake structures and screening facilities in handling fish; the causes of fish problems at such facilities; and the steps taken to rectify problems which have occurred. Careful consideration of biological information on species habit and behavior, species distribution, swimming capacity, water characteristics, operational effects, and predation during the siting and design stages can

greatly lessen the potential operational problem. Selection and siting of the intake, whether it be closed-conduit offshore, bankside, or approach channel, depends upon the topography, water quality, water levels and the ambient fish population. Vertical traveling screens, revolving drum screens, horizontal traveling screens, included plane screens, and coarse and fine fixed screens were discussed. Behavioral barriers such as electric screens, sound screens, light screens, air bubble screens, louver screens, and traveling cable screens were also covered. In general, it was concluded that the utility industry has relied on the conventional arrangement of trashracks, intake structure, and traveling vertical screens to prevent the entrance of trash, fish, and aquatic life with the cooling water into the condensers. There has been virtually no effort to evaluate the relative effectiveness of the protective systems either on overall basis or under various combinations of biological species, magnitude of flow, water temperature, site characteristics, and other factors.

Bechtel Inc. 1973. Application of mechanical systems to alleviation of intake entrapment problems. Seminar on the Engineering Aspects of Siting and Operating Power Plants, Washington, D.C. 44 pp.

An overview of the mechanical systems which provide either positive or behavioral barriers to the passage of fish or which can serve to guide or remove fish to areas of safety is presented. The following physical barriers are described: trash racks, vertical traveling screen, horizontal traveling screen, revolving drum screens, sound screens, light screens, air bubbler screens, traveling cable screens, and louver screens. Bypasses such as channel discharge, pumps, and elevators are discussed along with offshore, bankside, and approach channel intakes. Behavioral differences between species such as endurance, swimming speed, temperature tolerance, and ability to sense changes in the water environment must be considered. Intakes must be located in areas of low natural fish population. The discharge should be located away from the intake because fish are attracted to warmer water. Also, the depth from which water is withdrawn should be carefully selected.

Bell, M. C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fisheries-Engineering Res. Program, U.S. Army Corps of Eng., Portland, Oregon. 506 pp.

Bibko, P. N., L. Wirtenan, and P. E. Kueser. 1972. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (Morone saxatilis) and the gizzard shad (Dorosoma cepedianum). Westinghouse Env. Systems Dept., Pittsburgh. 16 p.

Bibko, P. N., T. Wirtenan, and P. E. Kueser. 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (Morone saxatilis) and the gizzard shad (Dorosoma cepedianum), pp. 293-304. In L. D. Jensen (ed.). Proc. Second Entrainment and Intake Screening Workshop, Baltimore, Maryland.

Studies on the swimming behavior of the striped bass (Morone saxatilis) and gizzard shad (Dorosoma cepedianum) are described. Objectives of the study were to (1) assess the influence of water velocity and

water temperature on fish swimming behavior and (2) to determine the efficiency of an air-bubble screen and intense illumination as deterrent devices which may be employed to reduce the frequency of fish impingement at operating power plants. Young striped bass were able to swim against currents ranging from 1.6 to 2.1 ft/sec for at least 10 min at 11.1 C without experiencing screen impingement. They experienced impingement at velocities of 2.2 to 2.8 ft/sec, but most survived when impingement time was less than 15 min. Young striped bass did not cross an air-bubble screen at 4.5 C or 11.1 C, but drifted passively through when the water temperature was 0.8 C. Gizzard shad did not cross the air screen at 11.1 C but continually passed through at ambient water temperatures of 0.8 C and 4.5 C. The air-bubble screen seemed equally effective during the day and during the night. Intense illumination only temporarily deterred fish passage.

Bier, P. J. 1954. Ice prevention at hydraulic structures, Part 1 and 2. Water Power 6:136-141.

The Bureau of Reclamation used two methods of ice prevention at dams, compressed air and electrical induction heating system. Compressed air systems effectively prevented or removed ice formation from critical areas of hydraulic equipment and structures at Grand Coulee and Black Canyon dams.

Bonisteel, W. D. and A. Bergs. 1961. Investigation of a compressed air bubbler system used for ice melting, pp. 78-99. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

Boreman, J. 1977. *Impacts of power plant velocities on fish.* FWS/OBS-76/20.1. 10 pp.

Air bubble screens and sound waves have not been shown to be effective measures for reducing impingement of fish.

Borodkin, B. S. 1955. Laboratory study of kinematics of deep water upwelling caused by air bubbles. Trans. Leningrad Inst. Water Transport No. 22.

Borodkin, B. S. 1956. Protection of hydraulic structures from effect of ice by application of compressed air. Trans. Leningrad Inst. Water Transport No. 23.

Borodkin, B. S. 1959. On design of a pipeline to a compressed-air breakwater. Trans. Leningrad Inst. Water Transport No. 26.

Borodkin, B. S. and B. K. Pavlov. 1959. Full-scale investigations of compressed-air facilities (CAF) at Kamskoye Reservoir. River Transport, No. 10.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn Univ. Agr. Exp. Station. Craftmaster Printers, Inc., Opelika, Ala. 359 pp.

Bramsnaes, F., J. Mogens, and C. W. Otterstrom. 1942. Barriers against fish by means of electricity or veils of air. Rept. Danish Biol. Stat. (Copenhagen) 47:41-46.

An attempt was made to regulate the passage of fish by means of an electric field. Rainbow trout, pike, carp, and eel were tested at a water depth of 90-100 cm, a current velocity of 5 to 6 cm/sec, and a voltage difference of 25 to 30 volts between the electrodes. The fish tested were very sensitive to electrical influences. Adequate voltage generally deterred the fish and made them evade the field. Ascending fish entering the field were only stunned and then carried out of the field by the current. They recovered quickly and showed no signs of being hurt. Fish found and used an insulated passage built beside the field. Experiments with barriers of air bubbles showed that trout were unaffected by the air curtain but carp and pike avoided it.

Brehmer, M. L. (undated). Ristroph traveling screen. Virginia Electric Power Company, Richmond, VA. 6 pp.

A modified vertical traveling screen was designed for the Surry Nuclear Power Station after a bubble screen and a sound screen proved ineffective in dealing with the unexpected impingement problem. A 10 gauge steel compartmented trough was bolted on the lip of a conventional screen basket so that a minimum of 2 in. of water was maintained during the time of travel from the water surface to the head shaft sprocket. On further rotation, a low velocity spray was used to wash fish into a a return trough. Continuous operation produced flow for fish transport back into the river away from the intake structure. Continuous operation reduced impingement time to two minutes or less. The screen wash system was also modified to minimize damage caused by the standard high pressure jets. Maintenance costs were higher because of the continuous operation, but the extra costs were felt to be justified by the environmental benefits (90.5% survival of impinged species).

Brett, J. R., and D. F. Alderdice. 1958. Research on guiding young salmon at two British Columbia field stations. Fish. Res. Bd. Can., Bull. No. 177. 75 pp.

Research on guiding young Pacific salmon while migrating downstream is described. Captive sockeye yearlings were tested in troughs to survey the reaction to light, sound, air bubbles, curtains of hanging chain, odors, dye releases and water velocity differences. Significant deflection resulted from the use of illumination at night, a band of rising air bubbles or bursts of dark dye during the day, and strands of chain hung vertically during both day and night. Experiments on hanging chains demonstrated that the maximum distance between strands which produced a deflection of 75% or better was 4 inches. The type of chain was unimportant, with the exception of its light-reflecting quality. The sensory stimulus causing the avoidance reaction was primarily visual. Slow oscillation of the chain increased the deflection of sockeye. Coho yearlings were not significantly deflected. Tests on cables suspended from a continuously moving belt were made at various intervals and rates of travel. The combination which proved most effective was an interval between strands of 6 inches and rates of travel from 8 to 12 inc/sec. Under these circumstances 92% of the sockeye and 59% of the coho were deflected. A new by-pass was built which improved

the trapping of deflected fish. Particular features of the by-pass were a reduction of visual cues in the entrance, gradual acceleration of the incoming water velocity, and the presence of cross-reflecting mirros. Tests were made on pink, chum and coho fry, as well as sockeye and coho yearlings. The same deflector was used with weighted cables, a minimum interval of 2-in. between strands, low direct-current charging of the moving cables, and a 3-ft wide sheet of metal on the stream bed, painted white to reflect incident surface light. No success was obtained in guiding any of the fry but both coho and sockeye fingerlings were deflected at a 95% level and higher. Some recommendations concerning the principles in the design of d^flectors and by-passes are set forth.

Brett, J. R. and D. MacKinnon. 1953. Preliminary experiments using lights and bubbles to deflect migrating young spring salmon. J. Fish. Res. Bd. Can. 10(8):548-559.

Experiments to deflect young spring salmon during their night-time migration by means of a beam of light and/or a wall of bubbles were conducted in a canal near Courtenay, B.C., Canada. By use of hoop nets it was discovered that under natural conditions no significant difference existed in the respective catches of the spring salmon underyearlings moving downstream on either side of the canal. A significant difference was obtained, however, when a narrow beam of light was directed into the water at a downstream angle in front of one net. A reduction to about one-third the expected catch resulted with either continuous or flashing light. The wall of bubbles, in a similar position, did not reduce the catch. Cutthroat trout fry and hatchery-reared Kamloops trout fingerlings were not deflected under these conditions.

Bronfman, A. I. 1957. Application of compressed air for clearing the ice from shipping lanes. River Transport, No. 12.

Brynildson, C. and J. Truog. 1960. The methods adopted to prevent winterkill of fish in Cox Hollow Lake, Iowa County, during the winter of 1960. Wis. Cons. Dept. Southern Area Invest. Memo. No. 254.

Bryson, F. E. 1975. Breaking the ice barrier. Machine Design 47(3):20-22, 24-25.

Installation of air bubble manifolds along the turn-of-the-bilge line in bulk carriers enables them to make passage through trash without becoming stuck.

Bulson, P. S. 1961. Currents produced by an air curtain in deep water. The Dock and Harbor Authority, May, pp. 15-22.

Cannon, J. B., G. F. Cada, K. K. Campbell, D. W. Lee and A. T. Szluha. 1979. Fish protection at steam-electric power plants: alternative screening devices. Oak Ridge National Laboratory, Oak Ridge, Tenn. (manuscript). 138 pp.

Fish may see a bubble curtain as a physical barrier and avoid it. Efficiency may be reduced at night or in turbid water. The bubble screen would be less effective for fish that are lethargic of heat-shocked.

Carstens, T. 1977. Maintaining an ice-free harbor by pumping of warm water, pp. 347-357. In Fourth Int. Conf. on Port and Ocean Eng. under Arctic Conditions, Vol. 1, St. Johns, Canada.

Cauthery, B. R. Undated. De-icing test rig. Roches Point, Lake Simcoe, Ont. Beardmore and Co. Ltd.

Cederwall, K. and J. D. Ditmars. 1970. Analysis of air-bubble plumes. Calif. Inst. Technol. Rep. KH-R-24. 51 pp.

Clapper, R. T. J., D. Smith, K. Stortz, and M. Sydor. 1975. Ice growth studies in Duluth-Superior Harbor 1974-75. University of Minnesota, Duluth. Report to NOAA PB-272170/2ST. 70 p.

The study concerns the investigation of the ice growth and heat budget in the Duluth-Superior Harbor. The Harbor, located at the extreme western end of Lake Superior, is one of the major shipping ports on the Great Lakes. It is ice bound from mid December to mid April, causing cessation of interlake shipping in the winter months. The Lake ice does not pose a severe navigational problem until ice packing occurs due to prolonged easterly winds in the early spring. Initial investigations on the feasibility of winter shipping in Duluth resulted in installation of an experimental bubbler system which was devised to keep the channels open in the early winter. However, the physical principles governing the ice growth in the Harbor are complex and not well understood. Problems arising in ice growth forecasting, design and construction of ice retarding methods, and evaluation of the environmental implications of winter shipping require a detailed investigation on the physical processes and the heat budget for the entire Harbor.

Clinch, R. L., R. N. Millman and O. M. Erickson. 1959. Ice problems at McCormack Dam. Proc. Eighth Congress Int. Assoc. Hydraul. Res.

Consolidated Edison Company of New York. 1970. Fish protection at Indian Point. Environmental Report Supplement for Indian Point Unit No. 3, Appendix S. 34 pp + app.

Systems tested included air bubblers, current velocity, fixed screens, light, seismic energy, and vertical traveling screens. Air bubblers were not very effective.

Corrigan, D. H. 1957. De-icing American waterways. River and harbours 42(12): 16.

Davis, A. 1918. Protection of Keokuk Dam gates from ice pressure by the use of air. Stone & Webster J. 22:199-206.

Dick, T. M. 1961. Description of air bubbling systems at Cambridge Bay and Tuktoyaktuk N.W.T., pp. 70-77. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

Dotson, W. A. 1961. Operational details of Project Polynya, pp. 58-69. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

Eccles, W. 1960. Can we break the St. Lawrence ice barrier? The Star Weekly Mag. April 16. pp. 20-23.

Enami, S. 1960. Studies on the bubble net II. Experiments on some sea water fishes performed on the driving and intercepting effects. Bull. Jap. Soc. Sci. Fish 26(3):269-272.

Laboratory experiments were conducted to determine the efficiency of air bubble curtains as a barrier and a means of guiding saltwater fish. It was determined that the efficiency of the curtain depended upon the ability of the fish to see the bubbles and the air pressure used.

Environmental Quality Laboratory, Inc. 1977. Mechanical mixing-aeration systems for destratifying and oxygenating dead-end finger canals. Evaluation report for General Development Corporation. 47 pp.

Fast, A. W. 1971. The effects of artifical aeration on lake ecology. Water Poll. Cont. Res. Ser. No. 16010, EPA.

Ficke, E. R. and J. F. Ficke. 1977. Ice on rivers and lakes-a bibliographic essay. U.S. Geol. Survey Water Res. Invest. 77-95. USGS/WRD/WRI-78/025, PB-279 528. 173 pp.

Ice on rivers and lakes influences design and construction of structures, operation of shipping, flow and circulation, water quality, and other factors related to the use of water. Human interest in understanding these influences has led to many programs of data collection, research, and investigations for a century or more. The body of literature reporting on these studies includes several thousand items in textbooks, proceedings, journals, and technical reports. By far, the largest portion of the studies were in the United States, Canada, or the Soviet Union. The literature can be classified as dealing with basic characteristics of ice; freezing and melting processes and their prediction and control on rivers, and on lakes; effects of river and lake ice on navigation, flow, and structures; and influences of ice on chemical, biological, and thermal aspects of water quality. This bibliography cites 750 publications, but the body of literature is large and this bibliography is not exhaustive. It does provide, however, a cross section of the scope of work in the field.

Fields, P. E. 1966. Final report on migrant salmon light guiding studies at Columbia River dams. Fish. Eng. Res. Program, U.S. Army Corps of Eng., Portland, Oregon. 267 pp.

Air-bubbler systems were not considered to be one of the more effective fish screening systems.

Frantsiya, G. 1926. Combating the effect of ice at flat gates of Rockwell HES (U.S.) by means of air-blowing equipment. Electrical World, Vol. 88:1175.

Gisiger, P. E. 1947. Safeguarding hydroplants against the ice menace. Civil Eng. 17(1):24-27.

Goldenberg, G. M. 1938. Blowing of water flow with air as a means of guarding sluices and locks against freezing. Bulletin of Technical Information, Glavgidroenergostroy No. 5:7.

Granbois, K. J. 1954. Experimental use of air bubblers for the control of sheet ice at Safe Harbor. In Proc. Eastern Snow Conf., Vol. 2.

Hackman, D. J. and R. L. Brunel. 1973. Design of a combination bubbler-guidance system to be installed in Whitefish Bay, Michigan. Battelle Columbus Laboratories Report. 7211-7301. 116 pp. NTIS AD773 345/4.

This report contains engineering descriptions, design details and cost estimates for the bubbler-guidance system.

Hanamoto, B. 1978. High flow air screen. Eng. Tech. Letter 1110-2-237, U.S. Army Cold Regions Res. Eng. Lab. 6 pp.

A high flow, high velocity air screen was installed across the upper entry on the Poe Lock at the St. Marys Falls Canal at Sault Ste. Marie, Michigan, to hold back downbound ice. The screen was less effective for 105-ft-beam ships than for 70-ft-beam ships.

Hanson, C. H., J. R. White and H. W. Li. 1977. Entrapment and impingement of fishes by power plant cooling-water intakes: An overview. Marine Fish. Review 39(10):7-17.

Air-bubble screens have generally been reported as unsuccessful at consistently diverting fish, although partial success has been observed.

Hess, P. M. 1953. Air bubbler system maintains open channel in ice sheet. Electrical World 139(10):106-107.

Heuritsch, K. 1960. Maintaining waterways ice-free by use of compressed air according to the 'dual pipe' system. Hansa, 97 XI, No. 45246, pp. 2310-2312.

Huber, E. E. 1974. Fish protection at intake structures and dams: guidance, screens and collection devices. ORNL-EIS-74-67. 75 pp.

Abstracts for eight air bubbler studies given in this selected bibliography are cited under author's names in this report.

Il'in, A. G. 1958. Compressed air facilities for maintenance of open places. River Transport, No. 3.

Imamura, Y., and M. Ogura. 1959. Study of the fish-gathering effects of air curtain. J. Toyko Univ. of Fisheries 45(2):173-177.

In experiments to determine the effects of an air bubble curtain on *Trachurous japonicus*, it was found that air bubbles are an effective tool for driving the fish. The curtain did not hold the fish in a particular position for a great length of time however.

Imamura, Y., and M. Ogura. 1959. Study on the response of *Trachurous japonicus* to air bubbles. J. Tokyo Univ. of Fisheries 45(2):195-203.

Experiments were conducted to determine the behavior of herring towards air bubbles with and without illumination. With high illumination,

the fish showed a tendency to gather near the air bubbles (79%), but tended to avoid the bubbles under low illumination (32%).

Ince, S. 1961. Recent experimental observations on the use of air bubbling systems, pp. 23-40. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo 70 (Ottawa).

Ince, S. 1962. Winter regime of a tidal inlet in the arctic and the use of air bubblers for the protection of wharf structures. Eighth Int. Conf. on Coastal Eng., Mexico. pp. 521-532.

Ince, S. 1965. A guide to the design of air bubblers for mel+ , ice, pp. 600-610. In Proc. Ninth Conf. Coastal Eng., Lisbon, Portuc .

Ince, S. 1967. A guide to the design of air bubblers for melting ice. Can. Inst. Mining and Metallurgy 10:19-21.

The mystery surrounding the success and failure of air bubblers is explained. On the basis of physical considerations, relationships are developed to help in the design of air bubbler systems.

IPC Business Press Limited (Editors). 1976. Icebreaking quarter from Nobiskrug. Marine Week 3(4):15-16.

A tanker is equipped with Wartsila's air bubble system and an icebreaker stem to penetrate ice without assistance.

Ismail, N. 1976. Guidelines for the design of air bubble systems. Proc. 15th Conf. Coastal Eng., Honolulu, Hawaii.

Jobson, H. E. 1973. The dissipation of excess heat from the water systems. J. Power Div., ASCE 99(PO1):89-103.

Kaitera, P. 1948. Keeping water from freezing by means of compressed air. Int. Union Geod. and Geophys., Int. Assoc. Sci. Hyd., Vol. 2, pp. 390-398.

Keribar, R. 1976. Suppression of an ice cover with heat transfer induced by a line source bubbler system. M.S. thesis, Northwestern University, Evanston, Ill. 56 pp.

Keribar, R., R. S. Tankin, and G. D. Ashton. 1978. Computer simulation of bubbler-induced melting of ice covers using experimental heat transfer results. Can. J. Civil Eng. 5(3):362-366.

Khubchandani, S. 1976. Presentation on MV Arctic. Can. Marine Transportation Adm. Report M2262-1 (CGVO-E).

An all purpose bulk carrier is double-skinned and equipped with a hull air-bubbler system to facilitate motion in ice. It will be the world's first heavy icebreaking cargo vessel, designed to operate in high arctic waters independent of icebreakers.

King, D. L. 1970. Reaeration of streams and reservoirs-analysis and bibliography. U.S. Bur. Reclamation REC-OCE-70-55. 131 pp.

Kobayashi, K., S. Igarashi, Y. Abiko, and K. Hayashi. 1959. Studies on air screen in water, I. Preliminary observation of behavior of fish school in relation to an air screen. Bull. of the Faculty of Fisheries, Hokkaido Univ. 10(3):222-228.

In order to determine whether air bubble curtains could be substituted for fish nets, experiments were conducted to attempt to intercept schools of fish with air bubbles and guide them into traps. Perforated pipes, 10-15 mm in diameter, were set in a tank and air was pumped into the pipes by a compressor. The air curtain was varied by changing the diameter and spacing of the holes as well as by changing the amount of air pressure used. Results showed that the air screen was capable of intercepting fish with a high degree of efficiency which was nearly equal to that of an ordinary net.

Kobus, H. E. 1968. Analysis of flow induced by air-bubble systems, pp. 1016-1031. In Proc. 11th Conf. on Coastal Eng., Vol. II, London, England. Am. Soc. Chem. Eng., NY.

Kobus, H. E. 1975. Air bubble screens as a tool for water quality control. In Proc. Second World Congress on Water Resources, New Delhi, India.

Kobus, H. E. 1975. On the use of air-bubble screens as oil barriers, pp. 356-363. In 16th Congress Int. ASsoc. for Hydraul. Res., San Paulo, Brazil.

Konovalov, I. M. 1946. Draft plan for prolonging the navigational period on the Angora River. Report of Sci.-Res. Council in Leningrad Inst. Water Transport.

Konovalov, I. M., V. V. Balanin, and B. S. Borodkin. 1954. Investigating the effectiveness of using compressed air for protecting hydraulic structures from effects of ice; on a laboratory study of the kinematics of upwelling of deep water by means of air bubbles. Leningrad Inst. Water Transport.

Konovalov, I. M., V. V. Balanin, B. S. Borodkin, and G. I. Melkonyan. 1957. Study and development of measures for protecting the locks and hydraulic structures from freezing. Tech. Rep. Leningrad Inst. Water Transport.

Konovalov, I. M., B. S. Borodkin, and V. V. Balanin. 1955. Preparation of test-experimental device for protecting the hydraulic structures from effect of ice with the aid of warm deep water. Tech. Rep. Leningrad Inst. Water Transport.

Konovalov, I. M., V. F. Teytelman, and N. P. Gilyarov. 1950. Study of the effectiveness of raising the deep water by air bubbles. Rep. Sci. Res. Dept. Leningrad Inst. Water Transport.

Krabach, M. H. and R. A. Marcello, Jr. 1976. An analysis of the feasibility of using air agitation to reduce gas saturations in sea water at Pilgrim Nuclear Power Station. Report to Boston Edison Company, Boston, Mass. 32 pp.

Kupfer, G. A. and W. G. Gordon. 1966. An evaluation of the air bubble curtain as a barrier to alewives. Comm. Fish. Rev. 28. p. 1-9.

The effectiveness of an air bubbler curtain to impede, redirect, or stop the annual migration of alewives in the Milwaukee River was studied in the spring of 1964. Its operation during a 1 1/2-month period indicated that the curtain reduced the migration of alewives.

Lackey, R. T. 1972. A technique for eliminating thermal stratification in lakes. J. Am. Water Res. Assoc. 8(1):46-49.

Lackey, R. T. and M. Levandowsky. 1972. Evaluation of two methods of aeration to prevent winterkill. Prog. Fish-Cult. 34(3):175-178.

Early aeration was more effective than late aeration to prevent winterkill.

Lake Michigan Cooling Water Intake Technical Committee. 1973. Lake Michigan intakes: Report on the best available technology. 45 pp + app.

The air bubbler system has proved to be inconsistent in preventing fish passage and should not be used as the basic screening device at power plants.

Lauri, A. H. 1961. Battling with a bubble gun: volleys from this improved air device unlock icy channels and combat stagnation. Compressed Air Mag. 66(1):26, 29.

A channel such as the St. Lawrence Seaway could be kept ice free at initial cost of $30,000 per mile plus operating costs of $750 per mile.

Lecourt, E. J., R. A. Major, H. L. Thomas, and J. N. Naegle. 1978. United States Coast Guard efforts to improve icebreaking efficiency. In Soc. Naval Arch. and Marine Eng. (eds.), Proc. STAR Symposium, New London, Conn.

Reduction of ice resistance to improve icebreaking efficiency was investigated. Optimum air flow rate for a bubbler system was determined.

Lewis, J. W. 1972. Ship model ice resistance experiments. Air bubbler hull lubrication for 1/20 scale model of Sundew. Arctic, Inc. Rep. TR-0029, 301 pp. NTIS AD-754 977.

Lieberman, J. T. and P. H. Muessig. 1978. Evaluation of an air bubbler to mitigate fish impingement at an electric generating plant. Estuaries 1(2): 129-132.

An air curtain was not an effective fish deterrent to impingement of three fish species examined.

Lorenzen, M. and A. Fast. 1977. A guide to aeration/circulation techniques for lake management. EPA 600/3-77-004.

MacGeary, D. 1958. Avoidance of ice formation on flat gates. Electrical World 110(27):12-13.

Marcy, B. C. and M. D. Dahlberg. 1980. Overview of best technology available for cooling water intakes. Report to Los Angeles Dept. Water and Power. NUS Corp., Pittsburgh, PA. 89 pp.

Screens of air bubbles have had partial success in some studies and no success in others in regard to blockage of fish movements. Effectiveness varied greatly with time of day, water temperature, and species of fish.

Marks, C. H. and D. C. Cargo. 1974. Field tests of a bubble screen sea nettle barrier. Marine Tech. Soc. J. 8(3):33-39.

Maxwell, W. A. 1973. Fish diversion for electrical generating station cooling systems, a state-of-the-art report. NUS Corp., Dunedin, FL. SNE-123. 78 pp.

Air bubbler system at a Green Bay power plant reduced the frequency of shutdowns caused by schools of alewife which shut off the flow of cooling water. Bubbler screens worked most effectively when they gave the appearance of a "milky white wall." Air bubble curtains were completely ineffective at the Indian Point Unit 1 on the Hudson River.

Mayo, R. D. 1974. Conventional fish screening systems and some promising alternatives, pp. 277-279. In L. D. Jensen (ed.). Proc. Second Workshop on Entrainment and Intake Screening. EPRI, Palo Alto, Calif.

A summary of power plant intake systems was given. Air curtains and sound barriers have been tried with variable claims of success. Little reliable data were available.

Mayo, R. D. and W. T. James. 1972. Rational approach to the design of power plant intake fish screens using both physical and behavioral screening methods. Kramer, Chin and Mayo Tech. Reprint No. 15.

Melkonyan, G. I. and B. S. Borodkin. 1961. Design of air lines at compressed air facilities (CAF) for upkeep of unfrozen water areas and wave suppression. Trans. Leningrad Inst. Water Transport, No. 13.

Merna, J. W. 1965. Aeration of winterkill lakes. Prog. Fish Cult. (Oct.): 199-202.

Michel, B. 1971. Winter regime of rivers and lakes. U.S. Army Cold Regions Res. Eng. Lab. Mon. III-B1A. 130 pp.

Summarized 20th century knowledge of river and lake ice surveys, heat balance on open water in winter, frazil ice, ice cover formation, ice breakup and ice control. Air bubbler was installed at Keokuk Dam in 1917. Water circulation at bubblers is described. Bubblers are used at dams, gates, piers and locks, and in ponds, marinas and lakes to prevent ice formation.

Mornington, S. 1929. Coping with ice at a hydraulic station. Compressed Air Mag. 34(7):19-20.

National Biocentric, Inc. 1973. Environmental impact assessment for Duluth-Superior Harbor. U.S. Army Engineers District, St. Paul, Minnesota. 269 pp.

National Biocentric, Inc. 1973. Environmental review report for demonstration of bubbler system in the Superior Entry, Duluth-Superior Harbor. U.S. Army Corps of Engineers, St. Paul, Minnesota. 108 pp.

The experimental bubbler was installed to evaluate its potential and utility in reducing the severity of ice cover and thereby extend the potential shipping season. That it was successful in meeting this objective is demonstrated by ship movement until January 1st. In addition, this study demonstrated that even though the bubbler was turned off on January 18th, ice breakup in the spring was earlier by approximately one to two weeks.

The bubbler resulted in a higher oxygen content throughout the depth profile. The higher oxygen content was apparently caused by the vertical circulation set up by the bubbler.

The higher oxygen content at lower depths should provide more favorable conditions for benthic organisms and fish. The results of the limited benthic analysis suggests an enhanced population in the region of the bubbler. Fish populations are not expected to be greately enhanced by an increase of 1 to 2 ppm in oxygen. The extended period of open water in the fall and earlier breakup in the spring will likely produce a longer period of fish mobility in the harbor in the fall and an earlier return in the spring. Bottom feeders will be supported by the enhanced benthos population.

The bubbler did not appear to have an impact in re-suspending particles from the sediments. The higher oxygen content of waters at the bottom is expected to enhance aerobic decomposition of organic material in the sediments. The vertical circulation established by the bubbler appeared to be effective in promoting distribution of soluble nutrients from organic decomposition. The bubbler did not, however, appear to be effective in re-suspending organic material, sediments or non-soluble nutrients.

The bubbler evaluation program was initiated on November 15, about one month before the bubbler was installed and operational. This limitation in time for planning, preparation and experimental design prevented many potentially useful studies from being implemented.

Future studies of fish, plankton, benthos, sediments and water chemistry should be planned to cover an extended period of time with more frequent sampling. Initiation of an evaluation program should be started in August and carried on at two-week (or more frequent) intervals until spring break-up.

A special evaluation program of the biological-chemical-physical impact of a bubbler should also be established in an area of quiescent waters. The present site at the confluence of the St. Louis and Nemadji rivers and near the entry to Lake Superior is subject to extensive natural and ship-induced turbulence. The high variance caused by these sources of turbulence makes definitive isolation and analysis of the effects of the bubbler difficult.

Fish were not studied but it was noted that certain species such as yellow perch, carp and some minnows could be expected in winter when anoxic conditions develop. Smelt, steelhead, walleyes and northern pike move into Superior Harbor in the spring.

Nybrant, G. 1959. Investigations on the water temperature at air bubbles systems in lakes. Proc. Eighth Congress Int. Assoc. Hydraul. Res.

O'Keefe, W. 1978. Intake technology moves ahead. Power (N.Y.) 122:50-54.

Ideas and equipment proposed or now in operation for fish protection at generating station intakes are discussed. Fish size is important because small fish require a fine screen and large fish that become impinged must be gently removed. Plant and intake siting, barriers of compressed air, light, sound, jetted water, pulsed electricity, and chains, along with conventional and novel screens, louvers, trash racks, pump .nd filtration may be considered in working up a design for a new modified power-plant intake.

Owen, T. 1942. Ice prevention by air-lift system at Grand Coulee. Trans. Am. Soc. Mech. Eng. 64(3):201-206.

Peschanskiy, I. S. 1969. Breaking the Russian ice. New Scientist 41, p. 574.

Gives information on dusting, bubbler system, and ice-cutters in the USSR.

Peterson, G. 1947. Use of compressed air at the TVA hydraulic stations (dams). Compressed Air Mag. 52(1):11-13.

Petrov, I. G. 1964. Use of deep-water heat for creating non-freezing water bodies. Leningrad Arkticheskii i Antarkticheskii N. - issl Inst. Trudy Vol. 267:81-88.

Pounder, E. R. 1961. Thermodynamic considerations on the use of air bubbling systems in salt water, pp. 41-46. In Proc. Symp. on Air Bubbling. Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

Pounder, E. R. 1965. The physics of ice. Pergamon Press, N.Y. 147 pp.

Chapters include introduction, sea ice, ice drift, ice control, crystallography of ice, mechanical properties of ice, thermal and electrical properties of ice, and growth and decay of an ice cover. Air bubbling was used in 1917 to protect spillway gates in a dam on the Mississippi River. The technique was "rediscovered" by Atlas Copco AB of Stockholm in the 1950's. Air bubbling of ice has been used for several purposes: to protect docks from ice damage, to permit winter construction on piers, to provide open water and dissolved oxygen for fish, and maintain short ferry channels.

Ray, A. A., R. L. Snipes and D. A. Tomljanovich. 1976. A state-of-the-art report on intake technologies. EPA-600/7-76-020. 82 pp.

This report reviews several studies which are cited elsewhere in this bibliography with the exception of the following reports. Field and laboratory studies were made by TVA to evaluate an air curtain for "leading, holding, and herding" fish. Carp and gizzard shad were contained significantly longer than largemouth bass and smallmouth buffalo. Carp were crowded into a small space before breaking through the curtain. Crowding of gizzard shad was less successful.

Tests designed to evaluate the effectiveness of an air curtain in guiding fish to a bypass were unsuccessful as the fish passed through the curtain. Fish readily passed under the curtain when it was off the bottom.

Impingement of alewife was reportedly reduced due to the presence of air bubblers at two power plants on Lake Michigan. At the Kewaunee plant, the bubbler was located around the periphery of the offshore intake. Schools of alewife occasionally broke through the barrier.

Alewife were thought to be diverted effectively by a bubbler system while larger fish were diverted by electric screens at the Michigan City power plant.

Reed (Thomas) Industrial Press Limited (Editors). 1976. Interesting observations on ship performance in ice. Ship and Boat Int. 29(12):39.

The effectiveness of bow propellors is due to the flow of water at the forebody of the vessel, acting as a lubricant for the ice/hull interface. The Wartsila air bubble system works on a similar principal.

Reisbol, H. S. 1975. Fish screens: The state of the art. I. Electrical World 183:155-156.

The need for the development of new concepts of intake design have resulted from legal requirements, guidelines and standards developed by regulatory agencies, major increases in plant size and volume of cooling water required, new biological design criteria, tremendous increases in capital and operating costs, and surveillance of plant operations by monitoring systems. New concepts have been developed for the three types of intakes: closed-circuit offshore, tankside, and approach-channel. The offshore closed-circuit intake usually has a screen well with vertical traveling screens located at the plant site onshore and a vertical intake tower with a velocity cap offshore. Approach velocities of about 1 1/2 ft/sec are optimum. Bankside intakes usually combine an intake structure with trash racks, fine screens, and pump wells on the banks of a river or lake. Approach-channel intakes may locate a trash rack and curtain wall at the head of the approach channel, while the fine-screening system is in the screenwell structure onshore. Air bubbles have been used in front of the trash racks. Velocities in the channel must be kept well below fish swimming capacity.

Reisbol, H. S. 1975. Fish screens: The state of the art. II. Electrical World 183:63-64.

Screen types and installations are of two types--physical barriers to fish passage and behavioral barriers to deflect or discourage fish. The vertical traveling screen is effective in screening fish provided that the mesh size, approach velocity, and structural installation are appropriately designed. The horizontal traveling screen consists of an endless belt of screen panels, traveling in a horizontal direction. A fixed fine-screening system

can be considered only where suspended debris is negligible, so cleaning requirements are minimal. A permeable dike built of loose rock or gravel provides an effective screen but has the disadvantages of relatively high cost and large size to accomplish the purpose. Behavioral or psychological screens depend on the fish reacting voluntarily or involuntarily to an external stimulus. Electricity, light, sound, louvers, traveling cable, and air bubbles have been tried but only air-bubble screens and louver screens have proven relatively effective at this time.

Richard, W. A. 1961. Ice-free Arctic harbors. Shipping Register and Shipbuilder (44)3.

Rossolimo, L. L. and G. S. Shilkrot. 1971. Effects of forced aeration on a hypereutrophic lake. Akademiya Nauk SSSR Izvestiya, Seryia Geograficheskaya No. 4, pp. 48-58.

Winter bubbling prevented thermal stratification, curtailed hydrogen sulfide, and retained areas of open water in a lake.

Schmitz, W. R. and A. D. Hasler. 1958. Artificially induced circulation of lakes by means of compressed air. Science 128(3331):1088-1089.

Compressed air is used in natural waters cheifly for reoxygenation or to remove ice from water surfaces. In winter, compressed air can be used to prevent winterkill. However, effects of low water temperatures on the fauna remain to be examined.

Senior, C. W. 1961. A model describing the physical processes of Project Polynya, pp. 47-57. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70 (Ottawa).

In regions where upward circulation of sensible heat is not a factor, as in Thule, Greenland, maintenance of an ice-free area is predominantly dependent upon the velocity and intensity of induced currents. Bubble systems were less effective than propeller techniques.

Sharma, R. K. 1973. Fish protection at water diversions and intakes: a bibliography of published and unpublished references. ANL/ESP-1. 35 pp.

Ten references are indexed to "air bubbles." They are cited elsewhere in this report.

Sigalla, A. 1958. Experimental data on turbulent wall jets. Aircraft Eng. Vol. 30:131-134.

Silberman, E. 1957. Production of bubbles by the disentegration of gas jets in liquid. In Proc. Fifth Midwestern Conf. on Fluid Mechanics, University of Michigan, p. 263.

Skerrett, R. G. 1923. Reducing ice pressures with compressed air. Can. Eng. 45:181-185.

Skerrett, R. G. 1923. Safeguarding a dam against harmful ice pressures. Compressed Air Mag. (January).

Smith, H. L. 1968. Babine Lake bubbler system. Eng. J. 51(3):39-45.

A bubbler system was used to keep open a two-mile-long ferry passage and landing area. Because of deep water, part of the bubbler line was moored at intermediate depths. Channel width varied from 40 ft at -30 F to 150 ft at 30 F.

Smith, K. A. 1961. Air-curtain fishing for Maine sardines. Commercial Fish. Rev. 23:1-14.

An air-bubble curtain for driving and guiding Atlantic herring (Clupea harengus harengus) from deep water to the areas where they could be taken in weirs and seines is described. Development, fishing methods, operation, and assembly methods are discussed. The air-bubble curtain consists of several lengths of 1/2- to 3/4-in. diameter polyethylene pipe, weighted to lie on or near the sea bottom, and from which columns of bubbles escape through 1/64-in. holes bored in the pipes at regular intervals. Air is supplied by a shipboard compressor. The bubble curtain is used to surround the fish and slowly draw them to the seines, or to otherwise direct them in the direction of the weirs and seines by cutting across their normal path of movement.

Sonnichsen, J. C., Jr., B. W. Bentley, G. F. Bailey and R. E. Nakatani. 1973. A review of thermal power plant intake structure designs and related environmental considerations. HEDL-TME 73-24, UC-12. 77 pp. + app.

Generally, the use of air screens has proven ineffective in restraining fish passage, particularly at night. Combined with other stimuli, they showed signs of usefulness.

Struct, M. I. 1969. The theory and design of bubble breakwaters, pp. 995-1015. In Proc. Eleventh Conf. Coastal Eng., Vol. II, London, England.

Superanskiy, N. M. 1942. Combating the effect of ice at hydraulic structures with the aid of compressed air. Pub. Scientific-Reclamation Inst. p. 8.

Swain, W. R., R. M. Wilson, R. P. Neri and G. S. Porter. 1975. Evaluation of the effects of a harbor bubble system for winter navigation on the water quality of Howard's Bay in the Duluth-Superior harbor, winter 1974-75. University of Minnesota, Duluth. Report to U.S. Army Corps of Engineers, St. Paul District Office, Minnesota. 64 pp. + appendices.

The major effect of the harbor bubbler system in Howard's Bay appears to be the minimization (damping) of large oscillations in the parameters measured. The bubbler system at this location did not appear to increase the levels of any of the parameters measured. Vessel traffic appeared to have a more significant effect on several of the major parameters than did the bubbler system alone. These included total and suspended solids, orthophosphorus, and lead values.

Levels of persistent organic compounds (nonionic chlorinated hydrocarbons), trace metals, and other chemical parameters were found to be quite low

in Howard's Bay. This may be due to two factors: Vessel traffic scouring the bottom of Howard's Bay, thus removing contaminated sediments, and/or relative lack of current causing a lack of influx of contaminants from other sites further upstream on the St. Louis River or other portions of the Duluth-Superior Harbor.

In the light of present data, there appears to be no major deleterious effect on water quality as a result of harbor bubbler operation. The location of the sampling site is considered singular and unique. Not only does bottom composition and topography play a significant role, but the relative lack of current, a major reason for selection of this site, is also a contributing factor. Extrapolation of data from this study to the rest of the harbor should be made with caution, but the following factors appear to favor wider application of the principle:

Resuspension of significant amounts of potentially contaminated sediments appears unlikely when the effects of the bubbler are weighed against other factors operative in the harbor, e.g., backflushing from major storms on the lake, river water run-off, industrial and municipal contributions, vessel traffic and the like.

Transport of sedimentary materials by either the Nemadji River or the St. Louis River, particularly during high water run-off, appears to hold a greater potential for deleterious effects than does the harbor bubbler system.

The normal passage of vessels, in particular deep-draft ships, appears to have a greater impact on water quality than does the bubbler system alone.

In some instances the effects of the bubbler system appears to be salutory by damping major oscillations of chemical parameters.

Sydor, M., B. O. Krogstad, and T. O. Odlaug. 1974. Evaluation of bubbler system for winter navigation, Howards Bay, Superior, Wisconsin, Winter 1973-74. University of Minnesota, Duluth. U.S. Army Corps of Engineers, St. Paul District Office, Minnesota. 59 p. + appendices.

There was an apparent seasonal change from January to March in the concentration of dissolved oxygen and nitrates at both the 5' and 25' depths. The results of the analyses of carbon dioxide, pH, alkalinity, total solids, and suspended solids showed a relatively constant picture over the period studied. Fluctuations in volatile solids between replicate samples at each of the three stations were relatively small. There was, however, an appreciable reduction in percent volatile solids from Station #1 to Station #3, as well as a seasonal reduction at Station #1 between February 23 and March 2. There is no apparent effect of the bubbler on the quantity and quality of the macrobenthos in the areas examined. The numbers of plankton show a general seasonal increase at the three stations. Both benthic and plankton organisms usually regarded as pollution-tolerant were numbered among the most predominant forms at all stations.

Symons, J. M. 1969. Water quality behavior in reservoirs, a compilation of published research papers. U.S. Dept. Health, Educ. and Welfare. U.S. Government Printing Office, Wash., D.C. 616 pp.

Tekeli, S. 1978. Air bubble screens. Ph.D. Thesis, University of Illinois at Urbana-Champaign. 204 pp. Diss. Abs. Int. 39/12-B, p. 6064.

Tien, C. and Y. Yen. 1974. Heat transfer analysis of air bubbler system, pp. 139-143. In Proc. Fifth Int. Heat Transfer Conf., Tokyo, Japan. Japanese Soc. Mech. Eng.

Toetz, D., J. Wilhm, and R. Summerfelt. 1972. Biological effects of artificial destratification and aeration in lakes and reservoirs-analysis and bibliography. Bur. Reclamation Rep. REC-ERC-72-33, Denver, Col. 117 pp.

U.S. Army Engineer District, Detroit. 1979. Survey study for Great Lakes and St. Lawrence Seaway navigation season extension. Draft Main Report and Environmental Statement.

Potential impact of air bubblers was assessed. It was considered to be a less important source of impact on benthos than dredging, vessel operation and icebreaking. Decreased ice thickness may increase phytoplankton production to a small degree. Long-line bubblers could interfere with fish migration if any refuse to cross the "air curtain."

U.S. Army Engineer District, Detroit. 1979. Survey study for Great Lakes and St. Lawrence Seaway navigation season extension, draft appendices, Vol II, Appendix I, Fish and Wildlife Report. 21 pp.

When operated constantly, bubblers probably would create open water areas which will attract waterfowl. Birds may die from malnutrition if aquatic and terrestrial foods are not available. This can be avoided by not operating bubblers until after water has frozen or by operating them intermittently. Bubblers may aerate the water thus attracting fish and other mobile animals; possible effects are not known.

U.S. Environmental Protection Agency. 1973. Development document for proposed best technology available for minimizing adverse environmental impact of cooling water intake structures. Washington, D.C.

This report includes a brief review of certain reports cited elsewhere in this bibliography.

U.S. Environmental Protection Agency. 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. EPA 440/1-76/015a. 263 pp.

The air bubble system appeared to be most effective in repelling schooling fish. However, the mechanism of bubble screening was not sufficiently well understood to recommend its adoption for power plant intakes.

Uziel, M. S. and E. H. Hannon. 1979. Impingement: an annotated bibliography. EPRI EA-1050 Project 877, ORNL/EIS-135 Interim Report. 193 pp.

This bibliography of 655 annotated references on impingement of aquatic organisms at intake structures of thermal power plant cooling systems was compiled from the published and unpublished literature.

The bibliography includes references from 1928 to 1978 on impingement monitoring programs; impingement impact assessment; applicable law; location and design of intake structures, screens, louvers, and other barriers; fish behavior and swim speed as related to impingement susceptibility; and the effects of light, sound bubbles, currents, and temperature on fish behavior. References are arranged alphabetically by author or corporate author. Indexes are provided for author, keywords, subject category, geographic location, taxon, and title (an alphabetical listing of keywords in context).

Voelker, R. P. 1973. Full scale tests of Great Lakes bulk carrier Leon Frazer in ice fields, 1972-73. Part 1: Trial manual. NTIS COM-73-10933.

Tests were made to determine if ice resistance can be reduced with an air coating or bubbler system. The manual describes the test plan, procedures, organization and schedule.

Voelker, R. P. and G. H. Levine. 1972. Methods to improve Great Lakes bulk carrier performance in mush ice fields and clogged channels, Vol. 1. NTIS COM-73-10937.

Objectives included developing methods for reducing bulk carrier resistance using air bubbler systems, water jet systems, and detachable bows.

Warner, G. 1956. Report on the air-jet fish-deflector tests. Prog. Fish Cult. 18(1):39-41.

An air jet fish deflector which made use of both bubbles and a noise making device was installed in Deer Creek to determine its ability to deflect salmon. Tests indicated it had little or no effect upon salmon movement.

Williams, G. P. 1961. A study of winter water temperatures and ice prevention by air bubbling. The Eng. J. 44(3):79-84.

This paper reviews information on the use of air bubblers to prevent ice formation. It was prepared for field engineers. Topics include water temperatures of lakes, rivers, and seas; design considerations; and experiments.

Williams, G. P. 1961. Thermal regime of lakes and rivers with reference to air bubbler systems, pp. 1-9. In Proc. Symp. on Air Bubbling, Nat. Res. Council Can. Tech. Memo. 70. (Ottawa).

Wirth, T. L., C. D. Russell, P. D. Uttermark, and W. Hilsenhoff. 1970. Manipulation of reservoir waters for improved quality and fish population response. Wis. Dept. Nat. Res. Rep. 62, OWRR Proj. B-013-WIS(4). 23 pp.

During the winter, air bubbling increased dissolved oxygen, reduced high concentrations of dissolved material near bottom, allowed invertebrate life in muds, and caused warmer waters to flow to the stream below the reservoir.

Wisconsin Natural Resources Department. 1968. Manipulation of reservoir water for improved quality and fish population. Wis. Nat. Res. Dept. Water Resources Res. Sec. Proj. Rep. 6 pp.

Winter air bubbling stirred the lake waters, maintained high oxygen levels, and prevented total freezeover.

Wortley, C. A. 1972. Lake Superior marinas resist ice and snow. Civil Eng.-ASCE 42(2):47-50.

Engineers faced problems designing two yachting marinas for the Apostle Islands area in southwestern Lake Superior in subzero weather. Sleeved piles and a dock de-icing system were installed. A compressed air de-icing system kept portions ice free.

Wortley, C. A. 1978. Ice engineering guide for design and construction of small craft harbors. Univ. Wisconsin Report WIS-SG-78-417. 125 pp. NTIS COMNOA PB-286 710/9ST.

Guide to design of small craft harbors. Includes information on operation and design of compressed air ice suppression systems.

Yemets, I. S. 1955. Concerning the operation of the air-blowing unit at Kegumskaya HES. Information Bull. Lumber Producers' Cooperatives, Gidrostal'proyekt.

Yunkind, P. L. 1935. Use of compressed air as a measure in counteracting the effect of ice cover at First Magnitogorsk Dam. Bull. All-Union Scientific-Research Inst. of Hydroengineering, Vol. 15, pp. 209-212.